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PROCESS DESIGN MANUAL FOR CARBON ABSORPTION

Swindell-Dressler Company

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Activated carbon adsorbs a great variety of dissolved organic materials found in wastewater, including many which are resistant to biodegradation in conventional biological wastewater treatment plants. Carbon's great efficiency in organic removal has promoted its use for upgrading conventional plant performance. Successful use of carbon in tertiary treatment has led to proposals that it be used for secondary treatment as well, i.e., as a replacement for biological treatment. In the latter instance, activated carbon would be used as one portion of a larger physical-chemical treatment plant.

This manual examines major design parameters and unit operations (including pretreatment) which are important in carbon adsorption systems. Existing carbon plant designs are evaluated. Costs are evaluated for the various unit operations. Various plant configurations are discussed. Carbon regeneration (a prerequisite for economic feasibility) is discussed and the necessary equipment is described. Other aspects discussed include: air pollution control devices for the regeneration furnace, personnel requirements, isotherm and pilot testing, carbon dewatering, biodegradation of organics in carbon columns.

(Schwartz/Taft Water Research Center)

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PROCESS DESIGN MANUAL
For
CARBON ADSORPTION

for the
ENVIRONMENTAL PROTECTION AGENCY
Technology Transfer

By
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FOREWORD

The formation of the Environmental Protection Agency marks a new era of environmental awareness in America. This Agency's goals are national in scope and encompass broad responsibility in the area of air and water pollution, solid wastes, pesticides, and radiation. A vital part of EPA's national water pollution control effort is the constant development and dissemination of new technology for wastewater treatment.

It is now clear that only the most effective design and operation of wastewater treatment facilities, using the latest available techniques, will be adequate to meet the future water quality objectives and to ensure continued protection of the Nation's waters. It is essential that this new technology be incorporated into the contemporary design of waste treatment facilities to achieve maximum benefit of our pollution control expenditures.

The purpose of this manual is to provide the engineering community and related industry a new source of information to be used in the planning, design, and operation of present and future municipal wastewater treatment facilities. It is recognized that there are a number of design manuals, manuals of standard practice, and design guidelines currently available in the field that adequately describe and interpret current engineering practices as related to traditional plant design. It is the intent of this manual to supplement this existing body of knowledge by describing new treatment methods, and by discussing the application of new techniques for more effectively removing a broad spectrum of contaminants from wastewater.

Much of the information presented is based on the evaluation and operation of pilot, demonstration and full-scale plants. The design criteria thus generated represent typical values. These values should be used as a guide and should be tempered with sound engineering judgment based on a complete analysis of the specific application.

This manual is one of four now available through the sponsorship of the Environmental Protection Agency to describe recent technological advances and new information in the following subject areas:

Carbon Adsorption
Phosphorus Removal
Upgrading Existing Plants
Suspended Solids Removal

These manuals are the first edition copies and will be updated as warranted by the advancing state of the art to include new data as it becomes available, and to refine design criteria as additional full-scale operational information is generated.

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ABSTRACT

The use of activated carbon for removal of dissolved organics from water and wastewater has long since been demonstrated to be feasible. In fact, it is one of the most efficient organic removal processes available to the engineer. The increasing need for highly polished effluents from wastewater treatment plants, necessary to accommodate the stringent requirements for both surface water quality and water reuse, has stimulated great interest in carbon treatment systems. Both the great capability for organic removal and the overall flexibility of the carbon adsorption process have encouraged its application in a variety of situations. It readily lends itself to integration into larger, more comprehensive waste treatment systems.

Activated carbon adsorbs a great variety of dissolved organic materials including many which are non-biodegradable. Adsorption is facilitated by the large surface areas on the carbon granules which are attributable to its highly porous structure. Biological degradation occurring on the granules complements the adsorption process in removing dissolved organic material. Carbon in certain configurations also functions as a filter. The greatest cost within the carbon treatment process is the cost of the carbon itself. Thermal regeneration of the spent carbon makes the process economically feasible; the cost of the regenerating equipment, however, represents only a small fraction of the total capital equipment cost.

The most important design parameter is contact time, the usual range being 15 to 40 minutes. Hydraulic loading, within the ranges normally used, has little effect on adsorption. The basic process configurations of the physical plant include upflow or downflow, either under force of gravity or pump pressure, with fixed or moving beds, and single (parallel) or multi-stage (series) arrangement.

Data from both pilot and laboratory tests, as well as experience from existing full-scale plants, must be carefully interpreted prior to the design of a new plant. Procedures for preliminary tests are discussed here, and the characteristics of some full-scale plants, planned or operating, are presented as well for illustrative purposes. Indications are that operating personnel requirements for the carbon portion of the wastewater treatment plant will not significantly increase the requirements for the entire plant.

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CHAPTER 1

INTRODUCTION

1.1 The Use of Carbon in Waste Treatment

Activated carbon can be used to reduce the pollutional load of many kinds of waste and raw waters. It is particularly well suited for removal of various types of dissolved organic materials. Most but not all dissolved organics can be adsorbed by carbon, and the exact degree of removal from the liquid phase depends upon a number of factors which will be discussed later. An important aspect of carbon adsorption is its capability of removing organics which are not completely removed by conventional biological treatment. Since biodegradable organics are also adsorbable, carbon can be used in either of two ways: to upgrade or to replace conventional biological treatment. In this manual, both applications will be considered, although the use of carbon in purely physical-chemical plants will be emphasized.

Carbon removes these dissolved organics through the action of two distinctly different mechanisms. The first of these is adsorption, which actually removes the dissolved organics from solution. Organic molecules in solution are drawn to the porous surface of the carbon granule by inter-molecular attraction forces, where the organics become substrates for biological activity. Biodegradation is thus the second mechanism by which carbon improves water quality. It is theorized that adsorption is the principal mechanism by which the dissolved organics are removed from solution and that biological activity functions as a regenerant of the adsorption sites by reopening the porous surfaces of the carbon. The exact mechanism is unknown, but a comparison between isotherm data and pilot plant data has shown that the biological contribution to the removal capacity is quite significant. Adsorption is probably predominant when a carbon column is first put into service. As operation proceeds, however, the biological process grows in importance as the numbers of the microorganisms increase. One can thus speak of a removal capacity different from and in excess of the adsorptive capacity of the carbon. The biological contribution to treatment may become as important as that of adsorption. However, this is speculation because as yet little performance data is available on biodegradation on carbon.

Wastewater treatment with activated carbon involves two major and separate process operations:

1.1.1 The Contacting Systems

The water is contacted with the carbon by passing it through a vessel filled either with carbon granules or with a carbon slurry. Impurities are removed from the water by adsorption when sufficient contact time is provided for this process. The carbon system usually consists of a number of columns or basins used as contactors. These are connected to a regeneration system.

1.1.2 The Regeneration System

After a period of use, the carbon adsorptive capacity is exhausted. The carbon must then be taken out of service and regenerated thermally by combustion of the organic adsorbate. Fresh carbon is routinely added to the system to replace that lost during hydraulic transport and regeneration. These losses include both attrition due to physical deterioration and burning during the actual regeneration process.

So far, the carbon process has been discussed in very general terms which apply equally well to either powdered or granular carbon. However, this design manual will be concerned exclusively with granular carbon. Despite their many theoretical similarities, the granular and powdered carbon processes present many strikingly different design and operating problems. For this reason, powdered carbon treatment will be considered separately.

1.2 Wastewater Characteristics

Contactors for granular carbon also function as filters for the removal of suspended material from the influent water. This is true only for packed bed (either upflow or downflow) contactors. Expanded bed upflow units do not function effectively as filters. If the incoming raw water contains appreciable suspended solids, these soon form a cake on the surface of a packed carbon bed. This clogging effect usually penetrates some distance below the surface of the bed. As this filter cake grows, it increases the pressure drop through the contactor. Backwashing is routinely necessary to reverse this situation. Expanded beds do not suffer from this problem.

Unless the suspended solids content of the raw water is very low, say less than 50–65 mg/l(1), it is usually advisable to employ dual-media filtration, chemical coagulation, or other particulate removal techniques before applying the water to the carbon bed. Activated carbon is too expensive to be used primarily as a filter medium.

Carbon's prime function is the removal of dissolved organics. However, while many organics are adsorbed, those molecules which are small or highly polar are not readily captured. Methanol, formic acid, or sugars for example, are not easily adsorbed. While most inorganics are not removable by carbon, some may be retained through precipitation or biological assimilation mechanisms.

The biological contribution to carbon treatment can also be greatly influenced by the chemical characteristics of the wastewater. Toxic substances might destroy all biological metabolisms and reduce the carbon's removal capacity to the same level as its purely adsorptive capacity. Another common inhibition to biological treatment might be the pH of the waste. For example, very high pH not only inhibits adsorption, but could also inhibit biological activity. This might occur in a system where a high pH chemical clarification step (e.g. lime) precedes the carbon step. To date, high pH wastewaters have been neutralized prior to carbon adsorption and so no particular reduction of adsorption capacity has been reported.

Unfortunately, our understanding of all these factors in the carbon treatment process is very incomplete, and it is not possible to accurately predict the treatment performance based upon a chemical analysis of the wastewater alone. Wherever carbon appears to be applicable, it is necessary to make a number of comprehensive tests, including at least a laboratory adsorption test and a pilot-scale evaluation (see Chapter 7).

In general, carbon can significantly improve the quality of most effluents from secondary biological treatment of municipal wastewater. Biological secondary effluent implies a water with less than 100 mg/l COD, and not more than 50 mg/l of suspended solids. If the waste contains any substantial amount of industrial effluent, the industrial contribution should be adequately characterized and taken into account during all preliminary testing.

1.3 The Place of Activated Carbon in Wastewater Treatment

Activated carbon is almost always a component in some larger wastewater treatment scheme. Since it is a relatively versatile process, it can be fitted into this larger system in a variety of ways. However, this versatility and its ability to produce a high quality effluent does not mean that it is a universal solution to all wastewater problems.

As has been noted, carbon has certain limitations to its ability to adsorb organics and to tolerate suspended solids. The biological contribution can be a distinct advantage. However, some adverse side-effects are possible if not controlled, such as sulfide generation. Therefore, the design of carbon systems must consider two different questions: the ability of carbon to adsorb organics from a particular waste stream, and the proper position of carbon in the total system.

It has already been suggested that carbon treatment can be used in either of two ways: to upgrade biological treatment or to replace it. The first of these two uses will more likely apply to an existing biological plant than to a newly constructed plant. Carbon adsorption is an excellent way to upgrade product quality in a biological plant unable to otherwise meet discharge or reuse standards; however, it should not be used as a substitute for optimizing the biological process. During the conceptual planning of a new plant, however, a purely physical-chemical treatment (PCT) scheme should be given serious consideration. In such a scheme, the sequence of basic processes is the same as in a conventional biological plant: gross solids removal, suspended solids removal, dissolved organic removal. The most obvious sequence of processes in such a PCT plant is: chemical clarification, filtration, carbon adsorption.

Carbon is usually thought of as a removal device for "refractory" organics, which refers to non-biodegradable organics. This definition of "non-biodegradable" becomes uncertain in a purely physical-chemical plant. Carbon removes biodegradable as well as non-biodegradable dissolved organics. When a non-biodegradable material is adsorbed on a carbon column with abundant biological activity, there is a much longer retention time available for biodegradation than would be the case in, e.g., an activated sludge system.

The following specific advantages have been suggested for PCT plants (which necessarily include activated carbon systems):

a) Land area requirements are much less than those for conventional biological plants, perhaps only one-fourth or one-third as much.

b) A wide variety of pollutants can be removed, many of which are refractory to conventional biological treatment.

c) Process control is much more reliable than in biological plants, and PCT plants are relatively insensitive to "upsets," changes in organic loading, or surges in flow. The PCT plants may therefore lend themselves to automation.

d) Plant expansion is more easily obtained because of the modular nature of the processes.

1.4 Effluent Quality

The effluent quality obtainable from granular carbon treatment depends on the character of the wastewater being treated. Therefore, in documenting the probable effluent quality of carbon plants, the nature of the raw wastewater and the effect of pretreatment must be cited. Table 1-1 shows some typical effluent quality data for various raw municipal wastewaters. Although the mass of data on purely PCT plants is somewhat scanty, it is clear that the product of a PCT plant (including carbon treatment) will equal or exceed that of a well-operated conventional biological plant.

No general rule can be given for the results to be expected from the treatment of industrial wastes, because this depends upon the particular chemical species present in the raw wastewater.

TABLE 1-1

TYPICAL PERFORMANCE OF GRANULAR CARBON TREATMENT

Feed	Influent COD (mg/l)	Clarifier effluent COD(mg/l)	Carbon effluent COD(mg/l)	Carbon contact time (minutes)
1. Raw	305	46	13	35
2. Primary	235	177	44	32.6
3. Primary	192	67	27	45
4. Primary *	50(TOC)	15(TOC)	4(TOC)	36
5. Secondary	30	N/A	8	40
6. Secondary	40	25	10	17

* upflow operation

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2. Rizzo, J. L. & Schade, R. E., "Secondary Treatment with Granular Activated Carbon", Water & Sewage Works, August, 1969 (p. 310)
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1. Recommendations by Hager, D. J. and Rizzo, J. L. of Calgon Corporation at Advanced Wastewater Treatment Technology Transfer Seminars, 1971.

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CHAPTER 2

GENERAL DESIGN CONSIDERATIONS

2.1 Variations in Flow

Streams of wastewater vary in their volume and chemical composition because of changes in the processes or in the events which generate these streams. These variations frequently exhibit clearly defined cycles. Municipal wastewater exhibits diurnal cycles corresponding to the life patterns of the population, which are, however, influenced by length of sewer and the size of the town. Industrial wastes may be influenced by the working hours of the plants, shift changes, week-end shutdowns, summer holidays, or fluctuations in production rates caused by seasonal marketing patterns. It is important to recognize that these fluctuations occur in the chemical character of the wastewater as well as in its volume.

Other fluctuations are related to changes in the weather, such as those due to ground water infiltration, illegal connections, and extraneous water entering the collection system.

Some provisions must therefore be made for dealing with these variations when a wastewater treatment plant is being designed. The major elements in a conventional plant are usually designed on the basis of the average expected flow during the design period of the plant. However, smaller elements such as the internal piping are designed on the basis of peak flows. Peak flows are frequently assumed to be 2-3 times the average flow.

In cases of above average flow, wastewater is permitted to pass through the treatment plant as usual, but the increased flow results in relatively poorer treatment and an unsatisfactory effluent is discharged for the duration of the surge.

One method of avoiding this impaired effluent quality is to construct a flow equalization basin. Excess flows or highly concentrated wastes could then be accumulated during surges and later be allowed to enter the plant gradually without impairing treatment efficiency. Equalization basins are probably advantageous in most situations, although they may be more necessary in complicated process sequences than in simpler ones. Some form of flow equalization may be advisable in any situation where the processes themselves cannot accommodate the variations in flow.

The requirements of flow equalization in a carbon treatment system are different from those in conventional biological plants or for other physical-chemical processes in two principal respects. First, since the carbon is usually preceded by one or more solids removal processes, these preliminary treatment stages act not only as pretreatment steps, but also to dampen variations in flow and organic loading. The reader is referred to the EPA Process Design Manual for Suspended Solids Removal for consideration of flow equalization with regard to solids removal processes.

Secondly, it should be recognized that the carbon process itself can accommodate significant variations in flow or organic loading without any substantial immediate disadvantage. At any given time, only a portion of the carbon contactor is actively engaged in the bulk of the adsorption, filtration, or biodegradation work. Any sort of excessive loading merely throws a greater burden on the portion of the carbon contactor which is less active in treatment, i.e., the downstream end. An organic shock loading may cause the column to be more rapidly exhausted, however, the effluent quality may not be seriously affected. If the carbon is close to exhaustion, effluent quality will be seriously affected.

However, this need be only a transient effect since the exhausted contactor would be immediately replaced by a fresh one. It may thus be desirable to build some excess capacity into the regeneration system for use during such organic surges in lieu of flow equalization. This is far superior to overdesigning the carbon contactors, since excess regeneration capacity is a much less significant capital item than are the contactors. (see Section 2.4). Surges in solids concentration which are not dampened by the pretreatment system are accommodated by increased backwash frequency.

The handling of sudden increases in flow rate through a carbon contactor present other problems for the designer. A pumped system will require additional capacity for flow and head in the feed pumps. In a gravity flow system, the energy requirements for increased flow can only be obtained by increasing the available head in the contactor. In conclusion it can be seen that the carbon plant can be designed to handle considerable fluctuations in wastewater organic concentration through the relatively inexpensive technique of installing excess regeneration capacity. The accommodation of large flow surges may be more expensive because of the problems associated with allowing for increased head. A good economic comparison of the relative costs of flow equalization basins versus increased plant capability for carbon plants has not yet been developed. At the present time, it is necessary for designers of carbon plants to evaluate several alternatives for a particular situation by making specific studies for that situation. However, as long as wastewater streams show variations in quantity and concentration, the question of flow equalization cannot be ignored.

2.2 Establishment of Design Flow

One of the more important design decisions which the engineer must make is the selection of the design flow for the carbon treatment plant. This question is intimately connected with those of handling diurnal variations in flow and of making an accurate forecast of the volume and character of wastewater which a community will produce during the course of the design period. The diurnal factor has been considered above. Selection of the proper design flow requires an analysis of the following factors:

1. Useful operating lifetime of the plant
    a. as influenced by wear-and-tear
    b. as influenced by technological obsolescence.

2. Interest rates and the rate of currency inflation, during the life of the plant.

3. Population changes in the service area of the plant during its useful life.

4. Changes in domestic living habits and consumer patterns (i.e., standard of living) during the plant's lifetime.

5. Changes in levels and types of industrial activity in the plant's service area during its useful life.

6. Changes in requirements for treated water quality during the plant's lifetime.

With an anticipated useful lifetime for the plant on the order of 20 years, at least from the standpoint of wear-and-tear, it is evident that accurate forecasts of the above listed parameters are difficult.

A better approach is to design for a relatively short term, taking into account only those future events and trends which can be foreseen with some precision. At the same time, the plant should be built so that its capacity can be increased as needed without scrapping or greatly changing the original equipment. The best way to accomplish this is by what might be called the modular approach to plant design. This means that plant expansion can be obtained by building a new plant beside the old one in parallel with it, with the flow proportioned between them. Physical-chemical treatment plants (and the carbon process in particular) readily lend themselves to the modular design approach.

Design capacity can be increased by more frequent regeneration of the carbon. In the original design, it is often relatively inexpensive to oversize the regeneration equipment and operate it initially on a part time schedule. As the treatment load grows, the utilization of the furnace can be increased until it is running steadily at full capacity. Another furnace can then be installed if needed. Of course, more frequent regeneration will add to total carbon replacement cost, but the cost per unit of water treated will not change greatly. Meanwhile, the capital cost is kept down.

The plant can also be expanded to accommodate a greater future flow by initially designing the carbon contactors to have slightly more than the minimum necessary freeboard. The initial capital cost for vessels is of course higher for this option. The original carbon inventory can be fixed at that needed for initial operation, however, thereby minimizing first cost. The resulting unused volume in the contactor vessels will not interfere in any way with operations. As the flow to be treated increases in the course of time or as its character changes, the carbon bed depth and the carbon inventory in the plant can simply be increased to keep pace with the flow. See Section 2.4 for the relative costs of various portions of the carbon system.

It is also possible to increase the treatment plant's capacity by adding additional contactor vessels as needed. The major requirement is that the initial design should provide space for the later addition of these vessels.

In summary, it seems best to design the major components of a carbon system for flow and water quality specifications which are based upon the present situation and only those short-term changes which can be accurately estimated. It is in the nature of the carbon process itself that later expansion can generally be handled economically.

2.3 Performance Specifications

It is important to prepare suitable performance specifications as part of the design of a carbon treatment plant. While this is a consideration in the design of any waste treatment plant, it deserves particular attention in the case of carbon. The carbon process has not yet been applied very widely, and so little experience can be cited from existing full scale plants. It is therefore important for the designer to conduct appropriate preliminary testing programs to cover his own situation. Municipalities or industries may be protected against deficient future plant performance only by periodic reevaluations of influent waste characteristics and plant operations. The same testing programs used during the initial design phase can be repeated whenever changes in the plant are anticipated. Such testing may include isotherm tests or even pilot column studies (see Chapter 7 for discussions of these tests). The carbon process provides the plant operator with a considerable degree of process control and flexibility which may help him to meet changing treatment requirements with a minimum of difficulty.

The design flow should be stated exactly and the plant should be equipped with a suitable flow meter. Design influent and effluent quality should also be clearly defined. Analytical and monitoring procedures to be used should be described in the specifications. The characteristics of the fresh and regenerated carbon should be specified. Carbon regeneration capacity may be stated, but the average regeneration rate and carbon usage can only be estimated. Both of these parameters will vary with flow rate and raw water quality – both of which will themselves fluctuate.

2.4 Distribution of Capital and Operating Cost Components

In designing a carbon treatment plant, many alternative schemes are available to the engineer. Optimizing the design becomes largely the problem of choosing among these alternatives. Capital and operating costs play important parts in this choice, but these considerations should be tempered by considering ease of operation, availability of personnel, reliability, etc. In making these decisions, it is helpful for the engineer to know the relative costs of various plant components. He can then direct his cost reduction efforts to the more expensive items before considering the less expensive ones.

The distribution of capital costs among the main operating segments of a typical plant are given in Table 2-1. Based upon a plant with 2-stage pressure downflow contactors(1), this analysis divides the total installed cost of the plant among three operating functions. All capital cost items in the design and construction of the plant (including engineering) are distributed among these functions.

The carbon contacting function includes costs for carbon inventory, contacting vessels and carbon storage facilities. The relative cost of the carbon inventory itself is, however, shown separately. The carbon regeneration sector covers the regeneration furnace, fans, air pollution control, and materials handling (including dewatering) at the furnace. The pumping function includes pipe, pumps and intermediate tanks. General materials such as foundations, structural steel, paint, instruments and building are distributed proportionally over the three functional areas. The costs for design, purchase, fabrication, shipment, and field construction for the complete plant are included in the appropriate categories.

Table 2-1

BREAKDOWN OF CAPITAL COSTS IN THE GRANULAR CARBON PROCESS

Function	% of Capital Cost
Carbon contacting	61
(Carbon inventory 20)	
(Carbon contactors and auxiliary equipment 41)	
Carbon regeneration	12
Pumps	27
Total Plant Cost	100%

The above cost distribution does not include any pretreatment facilities or equalization basins. It applies particularly to plants whose capacity is on the order of 10 million gallons per day. For smaller plants, the relative cost of the regeneration section will tend to rise.

Operating costs may be divided into a number of categories, including carbon replacement, power, fuel, labor, backwash water, maintenance, amortization, bond interest, etc.

Typical operating cost distributions are shown in Table 2-2.

Table 2-2

BREAKDOWN OF OPERATING COSTS IN THE GRANULAR CARBON PROCESS

Cost Component	% of Operating Cost
Carbon replacement	20
Operating labor	12
Electric power	12
Fuel	2
Backwash water	4
Maintenance	10
Amortization (20 years, 4%)	40
Total	100%

This situation is based upon the same type of plant as was used in the previous analysis of capital costs(1,2,3,4). No provision has been made for general overhead, bond interest, taxes, and insurance. The item shown for amortization can, of course, be changed to suit other depreciation bases as desired.

The backwash water cost shown presumes the use of carbon effluent for this purpose. However, the influent to the carbon process may be suitable for use as backwash water in many instances, e.g. when carbon is used as a tertiary process, or when the influent is well-clarified during pretreatment. The cost of using carbon effluent for backwash purposes must be recognized where this practice occurs.

An examination of the capital cost distribution clearly shows the great importance of carbon inventory in determining total plant cost. Changes in the amount of the carbon inventory will directly affect not only the inventory cost, but also change the size, and therefore cost, of the contact vessels and their auxiliaries. On the other hand, the total cost is not very sensitive to changes in the cost of the regeneration section.

The operating cost tabulation shows that carbon treatment is a heavily capitalized process, as indicated by the relatively large burden for amortization. The capital cost study showed that some 61% of the capital load is due to carbon contacting. Designers should direct their efforts particularly to this aspect of the plant.

2.5 Carbon Inventory

The "total" carbon inventory refers to the total amount of carbon actually at the plant site at any given time and is the sum of the "active" carbon and "idle" carbon. The active carbon is the amount of carbon that is actually engaged in the wastewater treatment process. "Idle" carbon is that portion of the total carbon that must be available in the system to ensure continuity of operations at the treatment plant. The minimum amount of idle carbon required for regeneration is equal to that capacity required for one spare contactor. An additional amount should be in storage for make-up to replace losses incurred during regeneration and handling. The amount of carbon held up in the regneration furnace itself is usually small, in some cases less than 1% of the total carbon inventory.

To effect a smooth and efficient operation during the regeneration sequence, it is customary to provide spare vessels, at least one of which is filled with carbon. When one vessel is taken offstream for regeneration, a spare vessel (already filled with carbon) is inserted in its place preventing interruption of service. The rearrangement of contactors in series is accomplished by installation of appropriate piping and valve arrangements so that any contactor can be taken out of service and any contactor can be used at the head of the series (See Section 5.9).

Investigations to determine the optimum amount of idle carbon have shown that minimum process costs result from systems in which 10% to 20% of total carbon inventory is "idle" carbon(5). Reduction in idle carbon usually is reflected in an increase in the number of onstream contactors. However, as additional contactors and associated piping arrangements are introduced to accommodate reductions in idle carbon beyond the optimum noted, the decrease in carbon investment is negated by the increase in contactor and piping costs.

2.6 An Additional Note on Carbon Regeneration

Since the relative capital cost of the regeneration portion of the plant rises sharply for the very small plant sizes (perhaps less than 1 MGD), the cost of the entire process may tend to become prohibitive. Two alternatives present themselves here. Either regeneration can be completely eliminated and the spent carbon discarded (a pilot evaluation and economic analysis could establish this to be feasible), or regeneration services could be purchased from an outside agency. The latter alternative might well be attractive for larger plants too. The carbon regeneration service need not be purchased from a commercial agency, but could be obtained by having several adjacent plants join in a regional cooperative venture for the purpose of sharing a regeneration furnace. Obviously, the saving in capital cost for regeneration equipment at the individual plants must be balanced against the costs of hauling spent and regenerated carbon to and from the regional facility.

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CHAPTER 3

PROCESS CONFIGURATIONS

3.1 Introduction

Carbon treatment of wastewater has been demonstrated for both municipal and industrial applications using several different process configurations. The options that are available to the design engineer include a choice between upflow and downflow, pressurized flow and gravity flow, packed beds and expanded beds, and series and parallel arrangements. Countercurrent flow, the optimum system for adsorption, may be closely approximated by a pulsed bed or by series arrangements in which contactors are progressively moved up in sequence as leading contactors are exhausted and removed from service.

The selection of the configuration for the final plant design should be confirmed by pilot plant testing under conditions closely simulating those of full scale (see Chapter 7).

3.2 Downflow

Downflow carbon beds accomplish both adsorption and filtration of wastewater. Plants using this mode of operation will utilize hydraulic loadings of 2 to 10 gpm/sq ft. At the lower flow rate, suspended solids contained in the wastewater are normally collected on the surface of the bed. At higher flow rates, some of the suspended solids may penetrate to some distance into the bed.

Provision must be made to periodically backwash downflow beds to relieve the pressure drop associated with the plugging by the suspended solids. Continued operation of a downflow bed for several days without backwash may compact or foul the bed sufficiently to make it more difficult to expand the bed during backwash without the use of an excessive quantity of backwash water, i.e., more than 5% of the product water.

In addition, biological growth taking place on the surface of carbon granules tends to clog the bed. Partial removal of these growths and control of their activity can be maintained by periodic backwashing, perhaps more frequently than once per day. Complete removal of the biological organisms cannot be accomplished by backwashing.

Assurance that aerobic conditions exist is possible through maintaining dissolved oxygen in the feed and in the backwash water. If anaerobic conditions develop, sulfides may be generated in the column and may appear in the effluent.

If the suspended solids concentration in the influent to the carbon beds is sufficiently great, the cost of backwashing must be weighed against the cost of providing a pretreatment step.

3.3 Upflow

Carbon beds operating with the wastewater passing upward through the carbon can assume three different modes. At low hydraulic loadings, less than 2 gpm/sq ft, the bed of carbon will remain substantially packed at the bottom of the column. At higher hydraulic loadings, 4–7 gpm/sq ft, the bed will become partially expanded. At much higher rates, the carbon will be lifted and packed against the top of the column. In the event that little or no freeboard is available, the bed will operate as a packed bed at any velocity.

When the upflow carbon column is operated as a packed bed, suspended solids present in the wastewater will be collected on the bottom of the bed. Unless preliminary solids removal processes are employed, backwashing of the solids from the bottom of the bed may pose a considerable problem, so these systems are not recommended.

Operating as a partially expanded bed, the carbon will not act as a filter. Suspended solids will pass into the effluent largely undiminished.

In the "pulsed bed" system, wastewater is passed upflow through the bed. Periodically, a column is briefly removed from service, a portion of the carbon in the bottom of the bed is withdrawn, and a fresh equal charge of carbon is forced into the top of the bed. As noted previously, this concept is one way of approximating true countercurrent operation.

3.4 Gravity and Pressurized Flow

The main advantage of a gravity flow system, which may be operated either downflow or upflow, is the elimination of large pumps and their associated operating costs, and the reduction of costs for non-pressurized vessels. However, due to the limited available head, it is usually necessary to remove suspended solids by pretreatment (e.g. through chemical clarification or filtration) so that headloss and thus backwash requirements are not excessive.

Operating a gravity flow system upflow as a partially expanded bed (rather than packed bed) is more attractive in that the pressure drop across the bed will remain constant. Thus this system can provide sustained operation over considerable periods of time. A supplementary solids removal step still may be necessary as either pre- or post-treatment.

Pressurized flow offers the advantages of being able to operate a carbon bed at a higher flow rate and over a greater range of pressure build up before backwashing is necessary. This permits the height of carbon contacting vessels to be limited to the carbon bed depth plus 50% for expansion during backwash.

In summary, the pressurized flow, at additional operating and investment costs, offers guaranteed flexibility in overcoming increasing pressure drops through packed beds. On the other hand, the gravity flow systems, although not fully evaluated at this time, offer considerable cost savings.

3.5 Single or Multi-Stage

The carbon contacting beds may be arranged in either single stage or multi-stage. The inclusion of adequate piping and valving in the design will permit switching from one mode of operation to the other if changes in the treatment objective are anticipated. The selection of the optimum design should be based on making maximum use of the carbon and providing the least expensive system that will yield the desired degree of treatment.

The series or multi-stage system will provide a higher degree of treatment and maximum use of carbon when greater removal of organics is required, above 90% removal of the total plant treatment system. Two previous economic studies (1, 2) recommend that a two-stage series is the least expensive design in terms of total operating cost. If the design objective is less stringent, then a number of single stage parallel contactors, staggered in their status of operation or degree of exhaustion, can produce an acceptable product by blending of individual effluents.

3.6 Carbon Regeneration Systems

The designer has few options available to him in the area of regeneration techniques and devices, and little in the way of design work is required. The most usual equipment is a multiple hearth furnace, which is adequate in most cases. For very small plants, however, capital cost may become prohibitive for thermal regeneration.Only two choices may be open to the designer for the case of small plants: he may consider the possibility of using the carbon only once and then discarding it rather than regenerating it, or he may consider the construction of a furnace which can be shared with another plant in the immediate area. See Section 5.2 for details on equipment and Appendix B for Furnace Specifications.

3.7 Carbon Transport Systems

3.7.1 Description

There are three conceptual transport systems for conveying granular activated carbon from the contacting beds to the regeneration furnace and returning it. In all instances, the carbon is transported as a carbon slurry through pipelines in accordance with the design principles to be discussed in Section 5.3, Carbon Transport. Carbon can be removed from contactors and conveyed through a pipe using pumps directly or through pump-eductor systems, as shown in Figures 3-1 and 3-2.

In Figure 3-1, the carbon is withdrawn from the bottom of a flooded contacting vessel by gravity. Maintaining the carbon in a fully inundated condition acts as a lubricant contributing to the fluidity of the carbon when it is withdrawn. This flow of carbon may be controlled by use of a rotary valve or by some type of diaphragm valve. The carbon enters the top of the eductor, mixes with the water as it is forced into the flowing stream, and is conveyed as a slurry to the drain bin.

The carbon after being drained for approximately four hours will have a moisture content on the order of 40%–50%. It may be discharged into a dewatering screw or a simple screw conveyor as shown. The conveyor, sometimes called a classifier, can serve two functions, that of further dewatering the carbon (not lower than the 40%) and that of controlling and conveying the rate of carbon feed to the regeneration furnace.

After passing through the regeneration furnace, the carbon is discharged into a quench tank and hydraulically transported to the regenerated carbon storage tank. The carbon is stored here until another contactor is emptied of spent carbon, then it is withdrawn and transported to the waiting vessel.

Figure 3-2 is a similar system which utilizes a flooded storage tank for the spent carbon. When the spent carbon is withdrawn from the storage tank, it must be passed over a dewatering screen or be discharged into the dewatering screw conveyor for further movement to the regeneration furnace.

Both the spent carbon storage tank and the regenerated carbon storage tank are eliminated in the system shown in Figure 3-3. Again the carbon must be dewatered by either a screen or a dewatering screw before entering the furnace. Upon the discharge from the furnace, the regenerated carbon is transported directly to a spare contacting vessel. In this system, a total of two spare contactors is actually required, one receiving regenerated carbon and one discharging spent carbon.

3.7.2 Comparison of System Requirements

In the first two cases, spent carbon is literally dumped from the contacting vessel into a temporary storage tank. This requires that the carbon slurry transport pipelines be of large diameter. In addition, the cost of one or more carbon storage tanks may be more than offset by the cost savings in reducing the number of spare contacting vessels required.

This cost tradeoff would favor carbon storage tanks over spare contacting vessels for pressurized systems, but it may be less favorable towards storage tanks in gravity flow systems, where contactors are less costly than in pressurized systems.

Whenever carbon is drained, it loses the aforementioned fluidity characteristics and may pose a potential problem in being readily removed from the elevated drain bin. The bridging of the carbon across the outlet from the hoppered bin may be prevented by proper design of the outlet, thus assuring continuous flow to the screw conveyor. In contrast, the flooded storage tank will have no such bridging problems. It will, however, deliver a carbon to the regeneration furnace with a 5% to 10% higher moisture content.

Control of the carbon feed to the furnace in Figures 3-1 and 3-2 is effected at the exit from the spent carbon storage tank or drain bin. Control of the carbon in the system without storage tanks, shown in Figure 3-3, is maintained by a rotary valve or a similar volumetric control valve at the point of discharge from the contacting vessel itself. Consequently, carbon transport from a spent carbon bed and to a spare carbon bed are carried on simultaneously while regeneration is taking place. This means that two spare vessels are necessary in the system. This slower mass flow rate of carbon through the carbon slurry pipelines permits the use of smaller size pipe for transporting the abrasive materials.

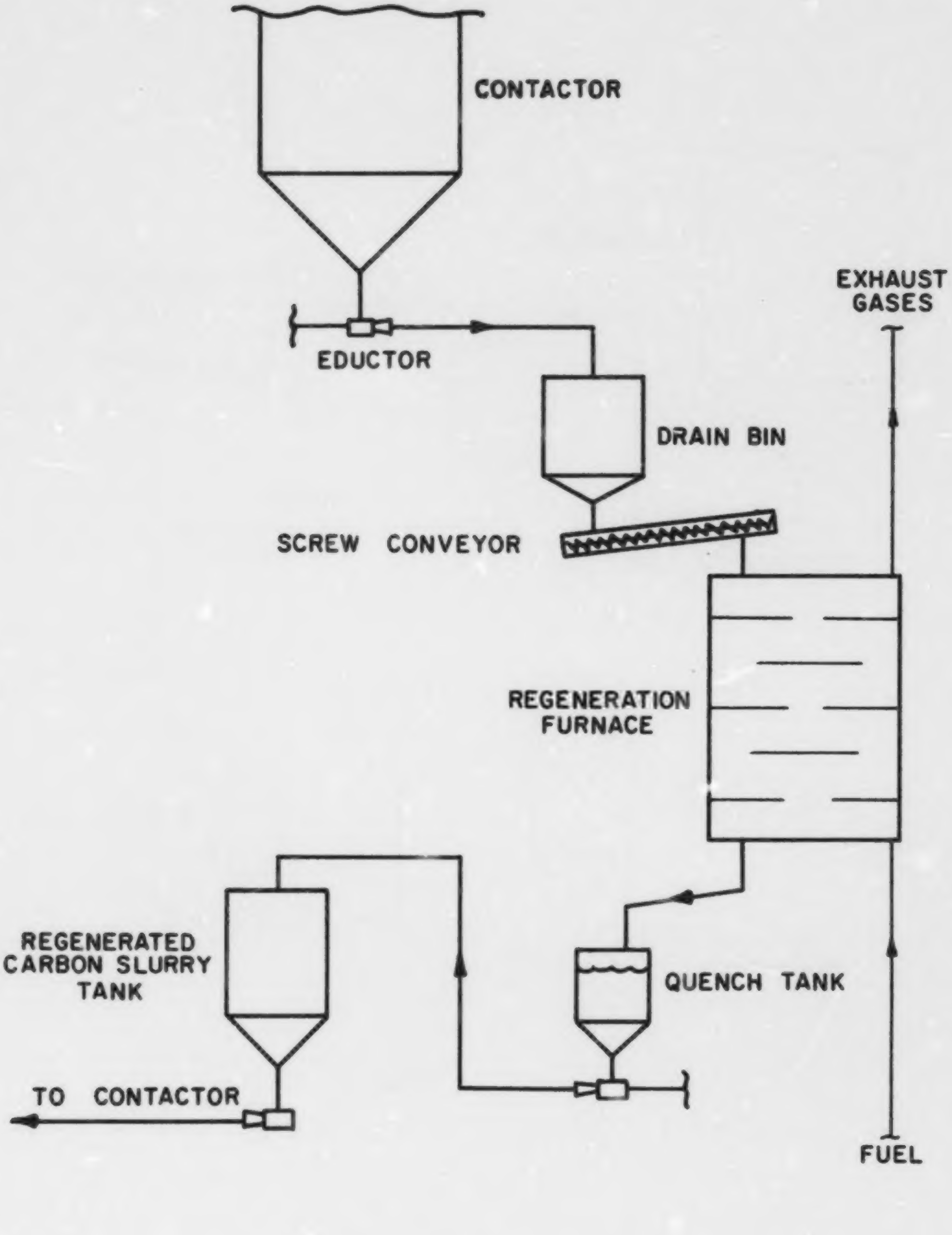
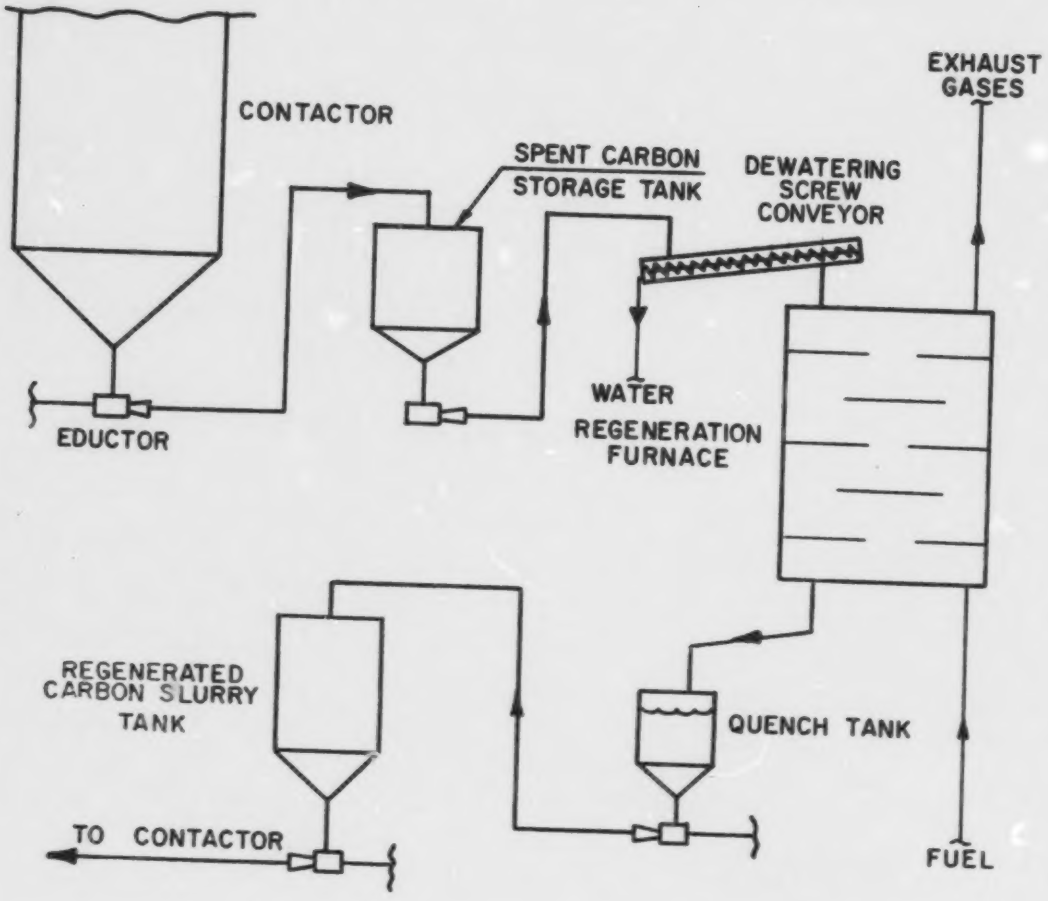
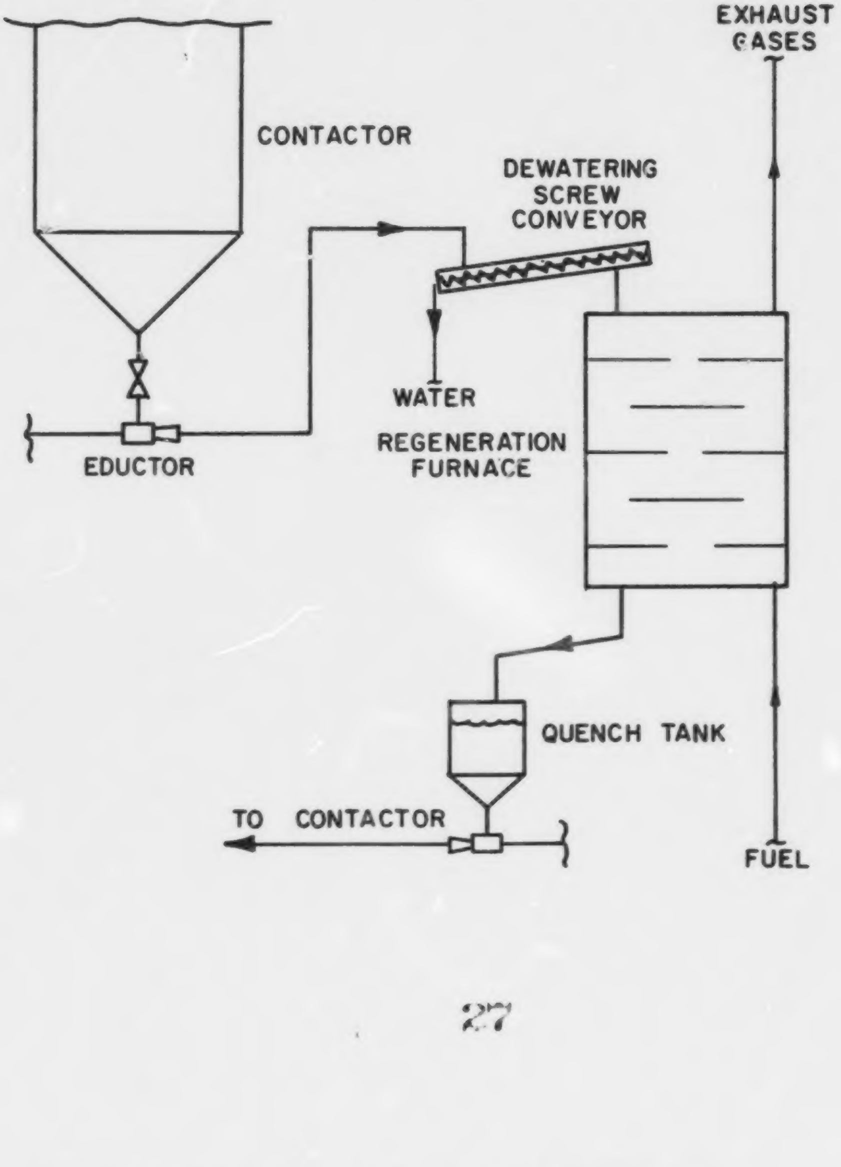

CONTACTOR
EDUCTOR
EXHAUST GASES
DRAIN BIN
SCREW CONVEYOR
REGENERATION FURNACE
REGENERATED CARBON SLURRY TANK
QUENCH TANK
TO CONTACTOR
FUEL

FIGURE 3-1–REGENERATION SYSTEM WITH DRAIN BIN


CONTACTOR
SPENT CARBON
STORAGE TANK
DEWATERING
SCREW
CONVEYOR
EXHAUST
GASES
WATER
REGENERATION
FURNACE
EDUCTOR
REGENERATED
CARBON SLURRY
TANK
QUENCH TANK
TO CONTACTOR
FUEL

26

FIGURE 3-2—REGENERATION SYSTEM WITH STORAGE TANK


EXHAUST GASES
CONTACTOR
DEWATERING SCREW CONVEYOR
WATER
REGENERATION FURNACE
EDUCTOR
QUENCH TANK
TO CONTACTOR
FUEL

27

FIGURE 3-3–REGENERATION SYSTEM WITHOUT STORAGE TANK

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CHAPTER 4

PROCESS DESIGN PARAMETERS

4.1 Carbon Properties

4.1.1 Raw Materials(1,2)

The most important design parameters for the carbon adsorption process obviously relate to the properties of the carbon itself. Before discussing these properties, it is necessary to consider what activated carbon is and how it is manufactured. Many of the properties of activated carbon are directly attributable to its origin and processing.

A wide variety of materials can be converted into activated adsorbents. These raw materials are all somewhat porous materials of carbonaceous origin. Examples include wood charcoal, coal, peat, lignite, bagasse, sawdust, cocoanut shells, bone, or petroleum residues. The better grades of carbon originate from coal, lignite, nutshells, and petroleum residues. Cheap solid waste materials such as pyrolyzed garbage have also been proposed for processing into activated adsorbents; however, these have not yet been tested very extensively. Cheaper raw materials of course tend to produce cheaper adsorbents; however, the costs of activation and aggregation into granules are such that the cost of granular carbon probably cannot be reduced significantly below its current level of 24-30 cents per pound. This does not apply so strictly to powdered carbon, which now costs 8-10 cents per pound.

4.1.2 The Activation Process(1,2)

The bulk of current domestic production of activated carbon is achieved by a high temperature steam activation process. The carbonaceous material fed to the activation process has already been charred. The steam activation process is usually carried out at temperatures of 750-950°C in an oxygen-depleted atmosphere. The reaction between steam and carbon is described by the equation

$$C + H_2O = H_2 + CO - 31 \text{ kcal.}$$

The reaction may be promoted by any of several dehydrating agents such as zinc chloride or phosphoric acid. An alternate activation scheme used more in Europe involves a lower temperature process at 400-600°C. This "chemical" activation procedure utilizes the dehydrating agents without benefit of steam or other oxidizing gases. The choice of method may be related to the raw material used. The production of an activated carbon of consistent quality and predictable properties requires a closely controlled activation procedure. The actual activation procedures in commercial use are much more complicated and are proprietary.

Once activated, the product is crushed or aggregated, graded, and washed with acid and then with water before being packaged. A variety of mesh sizes are available commercially. A photomicrograph of a carbon granule is shown in Figure 4-1.

The somewhat porous structure of the raw material is converted into the highly developed porous structure typical of activated carbon by the selective burning of the carbonaceous material. The resulting structure consists of a submicroscopic network of irregular pores within a graphitic crystalline matrix(1,3,4). The pore sizes cover a wide range from the

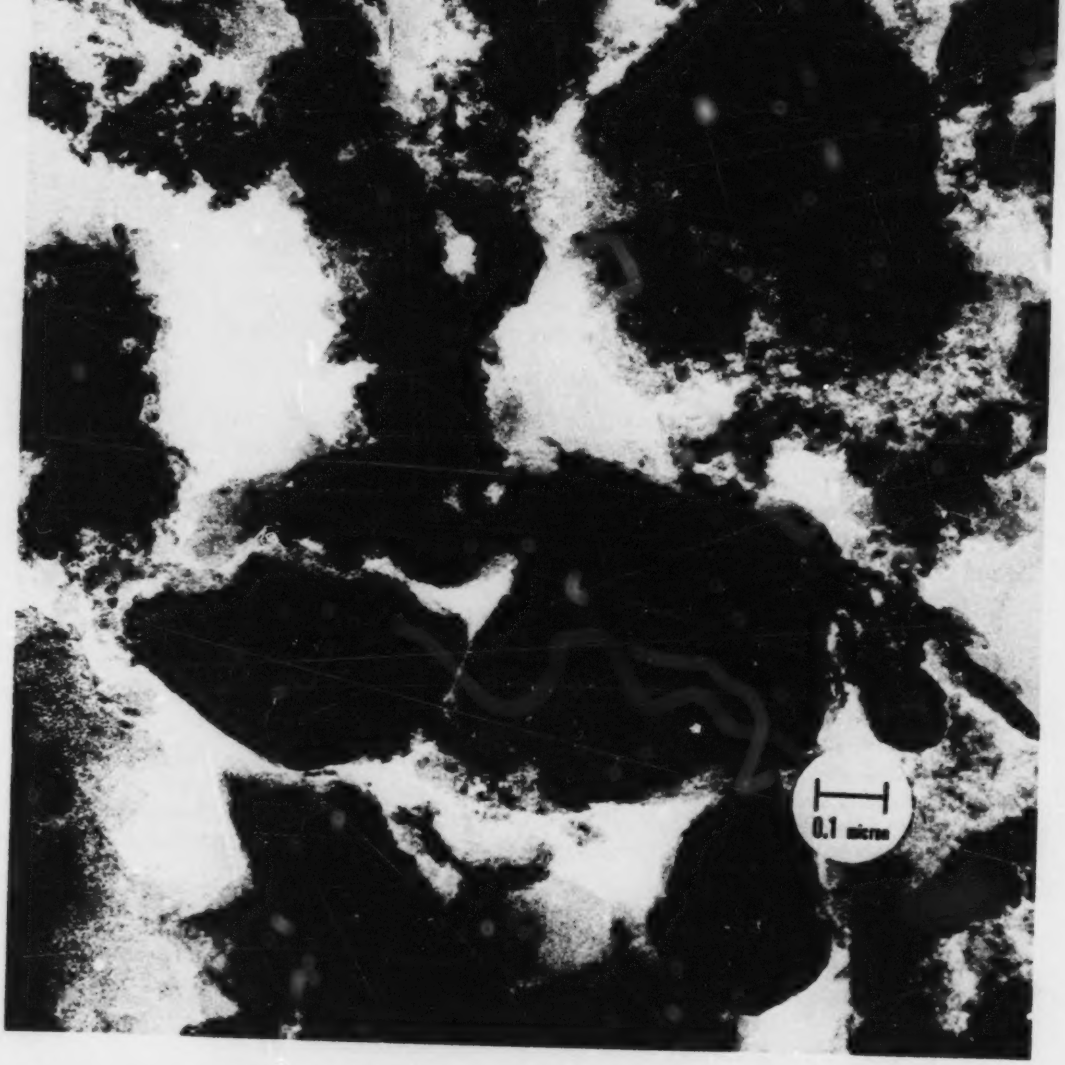

FIGURE 4-1–PHOTOMICROGRAPH OF CARBON GRANULES
(Photo courtesy of Calgon Corporation)

finest capillaries (less than 10 angstroms) to macropores (well over 1000 angstroms).

The highly adsorptive character of activated carbon is a direct result of this porous structure, which provides enormous surface area for adsorption. Adsorption of standard substances such as nitrogen gas or iodine solution can be used to demonstrate the existence of the porous structure, and also permit measurement of the pore diameters and surface areas. Intrusion of mercury and helium into the pores can be used to measure the pore volume. The pore structure will be considered further in connection with adsorption in Section 4.2.

4.1.3 Carbon Properties Relating to Its Use in Column Operations

Table 4-1 lists a number of physical properties of activated carbon which relate both to its adsorptive character and to its use in column operation. The data for these commercially available carbons is drawn largely from the manufacturers' sales brochures. The list of carbons is of course not all inclusive and is merely intended to illustrate some physical properties and specifications.

Particle size is expressed by several different parameters. It is measured by a sieve analysis in which a known sample of the granular carbon is passed through a succession of decreasing sieve sizes. The amounts of carbon retained on each sieve are weighed and the cumulative weight passed by a given sieve is plotted against the mesh size of that sieve on a semilogarithmic plot. Reading from such a plot, the sieve size which passes 10 percent of the total sample weight is the effective size. The 60 percent-passing sieve size divided by the effective size gives the uniformity coefficient. The 50 percent-passing sieve size is approximately the mean particle diameter, although this parameter can be obtained in other ways. The sieve size specifications which characterize the carbon are the U.S. Standard Sieve Series mesh numbers, e.g., 8x30, 12x40. The percentages of the sieved sample weight falling outside the ranges 8x30 or 12x40 are also shown in the Table.

The density of the carbon can be expressed in several different ways. The apparent density (see the Table) is the weight of carbon per unit volume which can be packed into an empty column. This can also be given in terms of a wetted, backwashed, and drained column. The real density is nothing more than the specific gravity of the carbon granule. The particle density (also shown) is the weight of carbon per unit volume of granule, including pore volume. The pore volume is also given.

Another physical parameter which pertains to carbon performance in column operation is the abrasion number, which is a measure of hardness (see Chapter 7 and the Glossary). The ash content represents inorganic residue remaining after activation.

4.2 Adsorption

4.2.1 Carbon Properties Relating to Adsorption(2,3,4)

As noted above, the surface areas available for adsorption in the porous structure of the activated carbon may be measured by several methods. The weights of different standard substances such as nitrogen gas, iodine, molasses, phenol, or methylene blue can be used to measure the surface areas in certain fractions or all of the pores. Nitrogen adsorption by the Brunauer-Emmett-Teller (BET) method is a measure of the total surface area of a carbon granule. Table 4-1 shows the enormous area of an activated carbon granule: over 1000

TABLE 4-1

SPECIFICATIONS OF SEVERAL COMMERCIALLY AVAILABLE CARBONS

	Atlas	Calgon Filtrasorb	Calgon Filtrasorb	Westvaco:		Witco
Physical Properties	**Darco**	**300**	**400**	**8x10**	**12x40**	**517**
Surface Area, m^2/g (BET)	600-650	950-1050	1000-1200	850	850	1050
Apparent Density, g/cc	0.38	0.48	0.44	–	–	0.48
Density, backwashed & drained, lb/cu ft	24	26	25	30	30	30
Real Density, g/cc	–	2.1	2.1	–	–	–
Particle Density, g/cc	0.67	1.3-1.4	1.3-1.4	1.4	1.4	0.92
Effective Size	–	0.8-0.9	0.55-0.65	0.90	0.65	–
Uniformity Coefficient	–	1.9 or less	1.9 or less	1.8	1.6	–
Pore Volume, cc/g	0.98	0.85	0.94	–	–	0.60
Mean Particle Diameter, mm	1.05	1.5-1.7	0.9-1.1	–	–	–
Specifications						
Sieve Size (U.S.Std.Series)						
Larger than No. 8-Max. %	–	8	–	2	–	–
Larger than No. 12-Max. %	5	–	5	–	2	*
Smaller than No. 30-Max. %	–	5	–	1	–	*
Smaller than No. 40-Max. %	5	–	5	–	1	–
Iodine No.	650	900	1000	850	850	–
Abrasion No., minimum	–	70	75	70	70	85
Ash, %	–	8	8.5	7	7	0.5
Moisture as packed, Max. %	–	2	2	2	2	–

*12x30 (no further details given)

Definitions of these and other terms are given in appendix A.

square meters per gram. The other standard adsorbates are used to measure surface areas associated with pores of given size. Iodine numbers are commonly used to measure regeneration efficiency since they are easier to run than BET tests. Iodine is adsorbed within relatively small pores and is thus a rough measure of total surface area. The iodine number coincidentally approximates the square meters per gram number from the BET test.

The vast majority of the surface area of an activated carbon granule is contained in the internal porous structure. This is true for all but the very smallest particle sizes. The size of the particle, therefore, has relatively little effect on the surface area.

The distribution of pore sizes can also affect adsorption. For example larger molecules can only penetrate into the largest pores. Smaller molecules can penetrate into smaller pores. Carbons with different pore size distributions can perform quite differently in adsorption tests depending on the size of the molecules to be adsorbed.

4.2.2 The Nature of Adsorption(2,5,6)

The adsorption process is the subject of extensive literature and a detailed discussion of it is not necessary here. It is sufficient to make a few remarks concerning the nature of the adsorption process and its application through activated carbon.

Adsorption is a process in which molecular or ionic species are accumulated on a surface and are thereafter bound to that surface by forces of molecular attraction. The area and properties of that surface govern the process of adsorption. For a given adsorbent, the adsorptive capacity is roughly proportional to the surface area available. The highly porous structure of activated carbon permits it to adsorb relatively large quantities of material per unit weight of carbon.

4.2.3 Adsorption Capacity

In an ideal situation, the adsorption capacity of activated carbon can be considered to be exhausted when removal of dissolved organics from the liquid phase ceases. At this point, the adsorbed molecules are in equilibrium with those in solution. In practice such a definition of the adsorption capacity on the basis of exhaustion is not so straightforward.

Adsorption of organics from municipal wastewater differs from adsorption from ideal solutions in two major respects. First, wastewater contains a broad spectrum of molecular weights of dissolved organics, so gross organic removal cannot be predicted on purely theoretical grounds. Second, wastewater is a biological fluid. Adsorbed organics are degraded through biological activity which occurs on the carbon granule. This process effectively increases the adsorption capacity over what would be expected in a non-biological fluid. These non-ideal characteristics of adsorption from wastewater can be illustrated by reference to Figures 4-2 and 4-3. Figure 4-2 shows a typical COD breakthrough curve in a carbon column in which the exhaustion of the column's adsorption capacity is well defined. Figure 4-3 shows a similar breakthrough curve from the EPA Pilot Plant at Pomona in which the exhaustion point is difficult to determine. It must be concluded that the proper definition of exhaustion should be set arbitrarily by whatever level of effluent quality is considered unacceptable.

The actual measurement (and prediction) of adsorption capacity is also complicated by the situation prevailing in column operation. In batch operations, wastewater adsorption

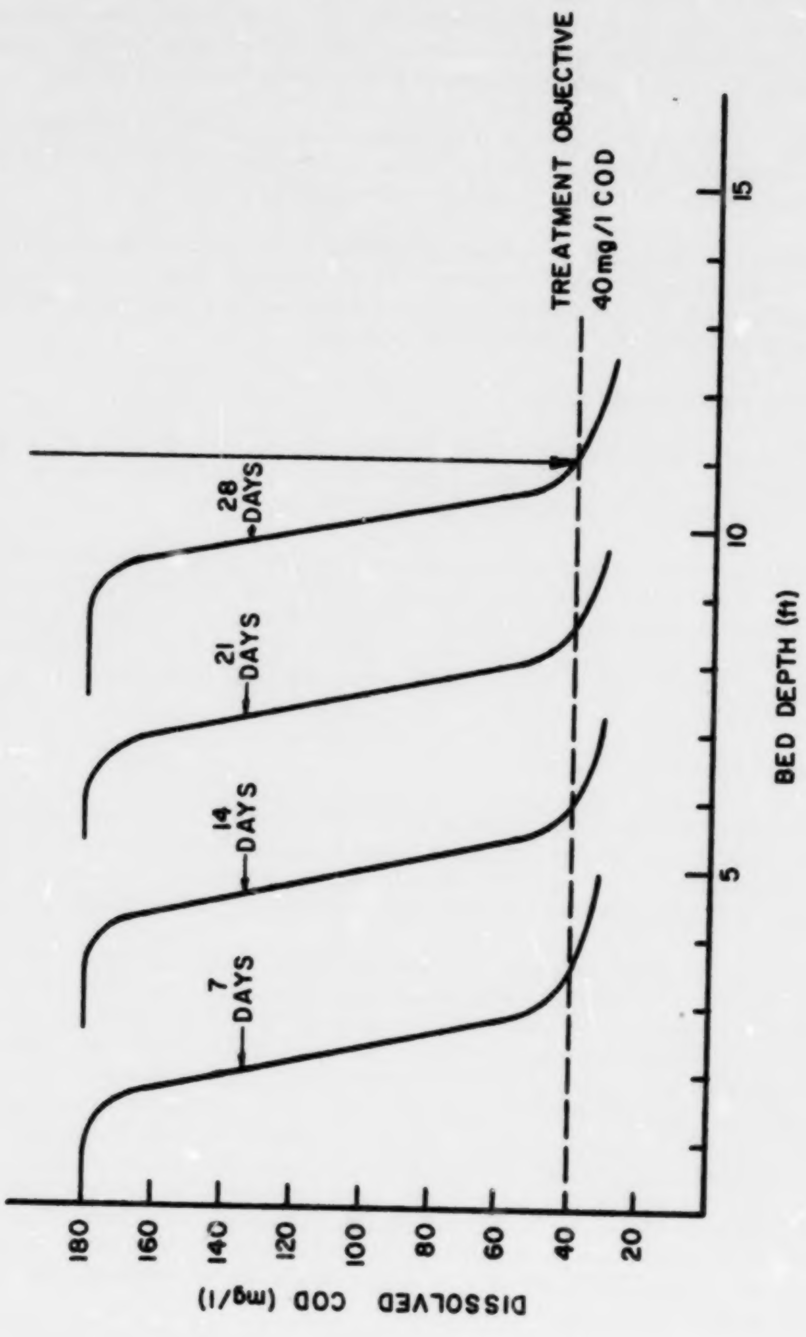

FIGURE 4-2–COD BREAKTHROUGH CURVES (IDEAL)

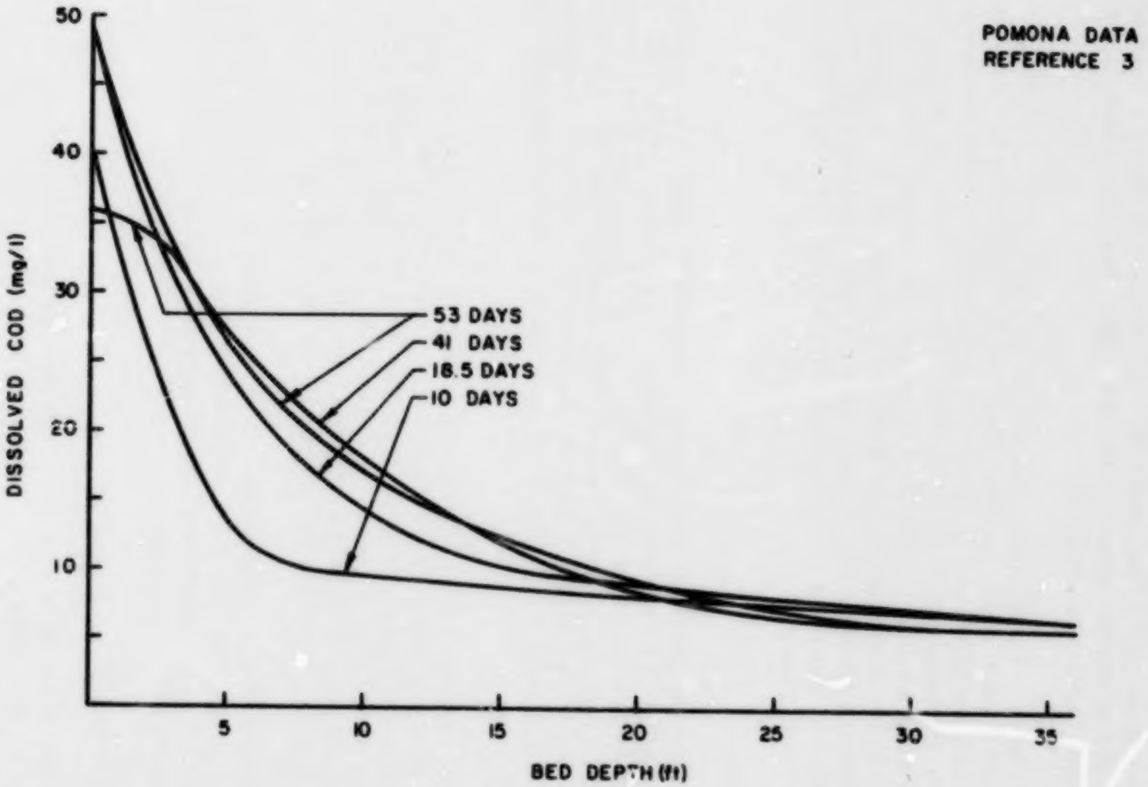

FIGURE 4-3–COD BREAKTHROUGH CURVES (NON-IDEAL)

isotherms can give well defined values for capacity. However, these values cannot be extrapolated to column operations. For tertiary treatment applications, reported values of adsorption capacity have covered the range 0.25-0.87 pounds of COD removed per pound of carbon(7). However, there is some evidence (not yet published) to suggest that secondary treatment applications of activated carbon produce COD loadings well in excess of 1.0 pound per pound of carbon(8). The contribution of biological treatment is responsible for these apparent high adsorption capacities. For this reason, the term "removal capacity" is probably preferable to adsorption capacity.

Carbon usually loses some adsorptive capacity upon regeneration. Combustion of the adsorbed organics is never really complete. Some ash accumulates in the carbon pores to obscure them and some carbon is burned up with the adsorbate, thereby decreasing carbon surface area. The net losses have been measured by English, et al(9), for the Pomona pilot plant in the tertiary treatment application. In a four-stage system, percent removal of dissolved COD in the lead contactor declined from 89 percent to 71 percent in two complete regeneration cycles, but thereafter remained virtually constant at 70 percent. This included the effect of makeup carbon. In a single stage system, the corresponding loss was from 53 percent to 47 percent.

4.3 Contact Time

The most important parameter affecting adsorption removal in columns is the contact time. The minimum contact time required for adsorption of wastewater organics by activated carbon depends on a variety of factors. These factors include: affinity of the carbon for a particular solute, degree of ionization, competition among solutes for adsorption sites, molecular sizes present in solution, surface area of the carbon, and distribution of pore sizes in the carbon. The required contact time must in actual practice be determined empirically in column tests.

In plotting organic removal versus contact time (synonymous with depth of carbon in this case) for the results obtained from a column test, the curve will be seen to break at some depth of carbon and remain relatively flat thereafter. Most of the adsorption taking place in the column occurs within this sharply defined zone, and little further organic removal may be obtained by increasing the contact time beyond this point. Figures 4-1 and 4-2 show how this zone changes with time in ideal and actual pilot column situations.

The contact time selected as a design value should be consistent with the precise degree of organic removal required. It should be conservatively in excess of the contact time at the break point on the curve, perhaps by a factor of about 2. The plant designs cited in Chapter 6 display a range of contact times from 15 to 40 minutes (empty bed).

4.4 Hydraulic Loading

Hydraulic loading is the flow through the column per unit cross-sectional area (usually gallons per minute per square foot). Hydraulic loading per se seems to have no effect on adsorption in the range 2 to 10 gpm/sq ft(7). Of course, in given column operation, changes in hydraulic loading which cause significant changes in contact time also affect the net COD removal in the column (see also Section 2.1).

Hydraulic loading is an important design parameter for reasons other than adsorption. The buildup of headloss in a downflow column is directly related to hydraulic loading, as shown

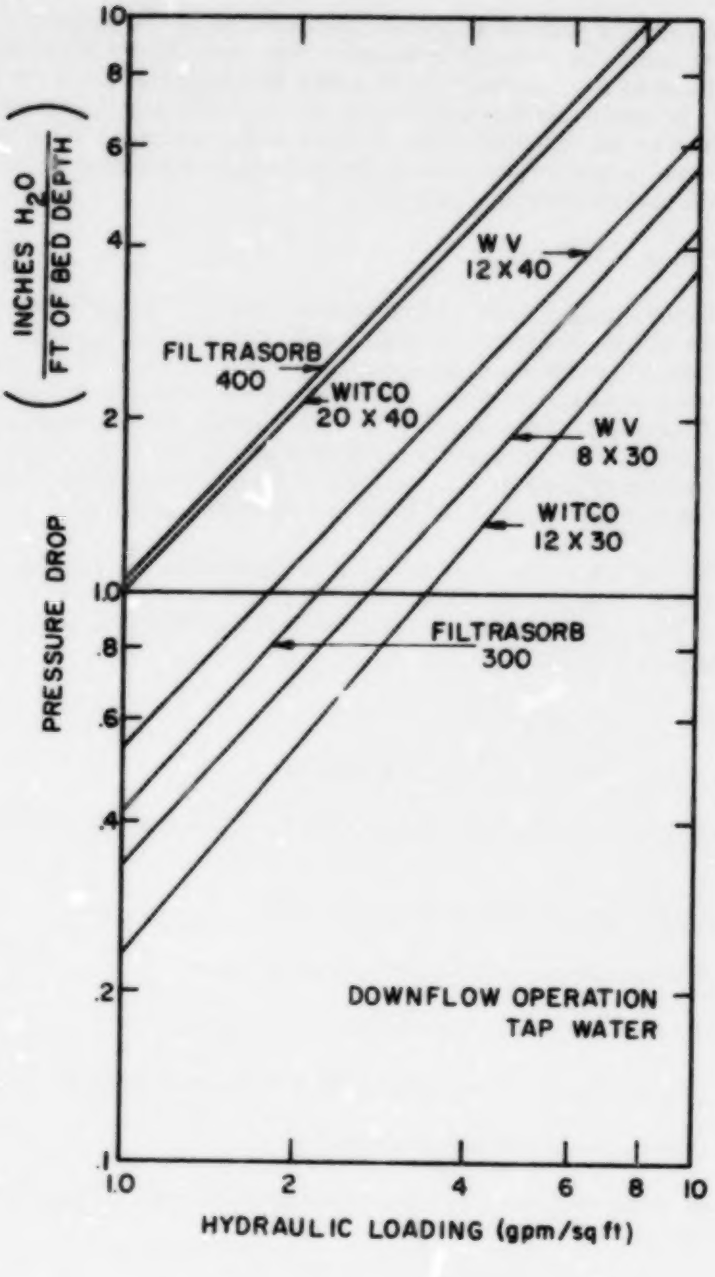

FIGURE 4-4–PRESSURE DROP VS HYDRAULIC LOADING

in Figure 4-4. These data are drawn from manufacturers' brochures and represent operation with tap water. The headloss for a given hydraulic loading with a wastewater feed must be determined by pilot testing.

Since headloss development is such an important consideration in the design of a carbon bed, hydraulic loading cannot be discussed in isolation from several other design factors. If an excessive rate of headloss development (due to a high hydraulic loading) is anticipated, an upflow bed should be given consideration. The choice of gravity versus pressurized flow may also be determined by the anticipated rate of headloss development. Higher hydraulic loadings are possible only in pressurized systems. Gravity flow is considered to be feasible only up to an hydraulic loading of about 4 gpm/sq ft.

4.5 Particle Size of Carbon

Particle size may have some indirect effect on adsorption capacity. The surface areas found on and in particles of various sizes may be slightly different, but this is not likely to be significant for the range of particle sizes employed for granular carbon (4 to 50 mesh). The distribution of pore sizes in various particle sizes of carbon may be different. The pore size distribution has an effect on adsorption capacity and rate, since the penetration of adsorbate molecules into the porous carbon structure is governed partially by the respective sizes of molecule and pore (see above Sections 4.1.2 and 4.2.1). The effect on adsorption usually attributed to carbon particle size may in fact be due to pore size distribution.

In selecting a particle size for use in pilot or full scale application, the headloss incurred through the bed is of primary importance. Therefore, the particle size cannot be discussed in isolation from flow configuration (upflow versus downflow), hydraulic loading, and gravity of pressurized flow (see Chapter 3).

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CHAPTER 5

EQUIPMENT DESIGN

5.1 Contactors

The size, number, shape and configuration of vessels to contain carbon are selected on the basis of physical capacity, hydraulic loading, contact time, feed characteristics, pretreatment, desired product quality, mode of operation and relative economics.

Economic analysis has shown that there is no apparent advantage of shop-fabricated over field-erected vessels. A maximum diameter of 13 feet is imposed by transportation clearances for shop fabricated vessels. The apparent savings of larger diameter vessels which require less inter-vessel piping and valving, may be offset by the additional "idle" carbon required to fill a larger spare contacting vessel.

The desired product quality will establish the required contact time and hence the approximate total carbon volume which actively contacts the wastewater. The hydraulic loading selected will fix the total cross-sectional area and total carbon bed depth.

The designer has the option of converting the total carbon bed depth into one or more bed depths in series and the overall cross-section of the carbon bed into several beds in parallel.

The height of each vessel must be sufficient to permit expansion of the carbon bed during backwash in a downflow bed, or to allow proper expansion of an upflow bed during service. The vessel should be designed to permit up to 50% expansion during backwash to assure that accumulated suspended solids can be disengaged from the surface of the carbon particles.

The vessels should be arranged with inlets and outlets oriented to accommodate internal distributors and external piping systems. Although conical bottoms in vessels facilitate removal of carbon by slurry discharge, flat or dish-shaped bottoms provide more efficient distribution during service and backwash operation.

If nozzles are used as the means of collecting the wastewater after it passes through the carbon bed, they should be screened so as to retain carbon in the 60 to 80 mesh range.

When flat porous bottoms are used, an arrangement of funnels through the bottom may be employed to remove carbon from the vessel for regeneration. Filter bottom designs used in rapid sand filters should be considered for use in carbon contactors.

Special screens and, on occasion, dual screens have been utilized in lieu of the porous or perforated filter bottom. These screens should be designed to physically support the carbon during service operation, and to allow maximum backwash velocity, thus enhancing the cleansing capability of the system.

Figures 5-1 through 5-4 depict the contacting vessels used or designed for the granular carbon wastewater treatment plants at Pomona(1), Lake Tahoe(2), Colorado Springs(3) and Rocky River(4). Of primary interest is the design of the bed inlet and outlet to assure ease of carbon removal and proper water distribution. These two objectives present conflicting design requirements, for the best design for each cannot be achieved simultaneously.

The Pomona contactor (Fig. 5-1) with a 1.5 bed depth to diameter ratio (L/D) offers good distribution of wastewater across the bed during service operation. The Neva-Clog-Screen at the base retains the carbon in the bed and provides a perforated surface through which the wastewater passes before entering the underdrain systems. During backwash the Neva-Clog-Screen provides a distribution of the wastewater across the bottom of the bed.

This screen system, or a perforated plate, or any other bottom support system must also be designed to distribute the backwash water at the maximum anticipated rate and to withstand the associated uplift force. The maximum backwash velocity at Pomona, 12 gpm/sq ft, although adequate for expanding 16 x 40 mesh carbon, is not sufficient to provide 50% expansion of 8 x 30 mesh carbon. Even if backwash pumps were sized to force an upward flow of 20 gpm/sq ft through the carbon beds, the excessive pressure drop across the screens or plates might force them to warp or to be dislodged. Special consideration is required to assure that these types of bottom support systems can hydraulically handle maximum flows in both directions and are adequately held in place.

Removal of the major part of the carbon from the carbon bed is facilitated by keeping the bed flooded during withdrawal operations. The removal of the last stump or heel of carbon in the farthest corner of the bed from the withdrawal port may be difficult. A supplementary backwash (upflow) on the order of 3 to 6 gpm/sq ft or nozzles in the side of the column just above the underdrain system may aid in flushing this last quantity of carbon from the beds.

The Tahoe design (Fig. 5-2) is applicable to either upflow or downflow operation. The conical bottom offers the greatest ease of removing spent carbon from the bed at a possible sacrifice of initial distribution of water across the bed during normal operation.

The angle of repose of granular activated carbon immersed in water is sufficiently steep that conical bottomed vessels must be designed with minimum bottom slopes of 45 degrees. Although the carbon will flow when completely inundated, the use of shallower angles is not recommended.

The Colorado Springs contactor (Fig. 5-3) and the Rocky River contactor (Fig. 5-4) both offer a flat bottom support for the carbon. Funnel shaped ports through the support are provided for carbon removal. The effectiveness of this type of system in withdrawing carbon has not been proven in actual operation at this time.

The actual bottom support system utilized is different for the two contactors. The Colorado Springs contactor (Fig. 5-3) employs a perforated stainless steel plate into which Eimco's Flexkleen nozzles are inserted for backwash control and distribution. In contrast, the Rocky River contactor (Fig. 5-4) employs a porous tile filter bottom covered with several inches of graded gravel and sand.

Gravity flow contactors are designed similarly to concrete rapid sand filters. A typical gravity filter design is shown in Figure 5-5. The requirements to be satisfied in carbon contacting are an adequate side wall depth to provide for 50% bed expansion during backwash and a means for drawing off the spent carbon to be regenerated. Carbon can be removed from the contactor through a trough on top of the underdrain system or the installation of funnels similar to those employed at Colorado Springs or Rocky River.

Distribution problems, i.e., channeling, at low flow velocities cannot be determined at this

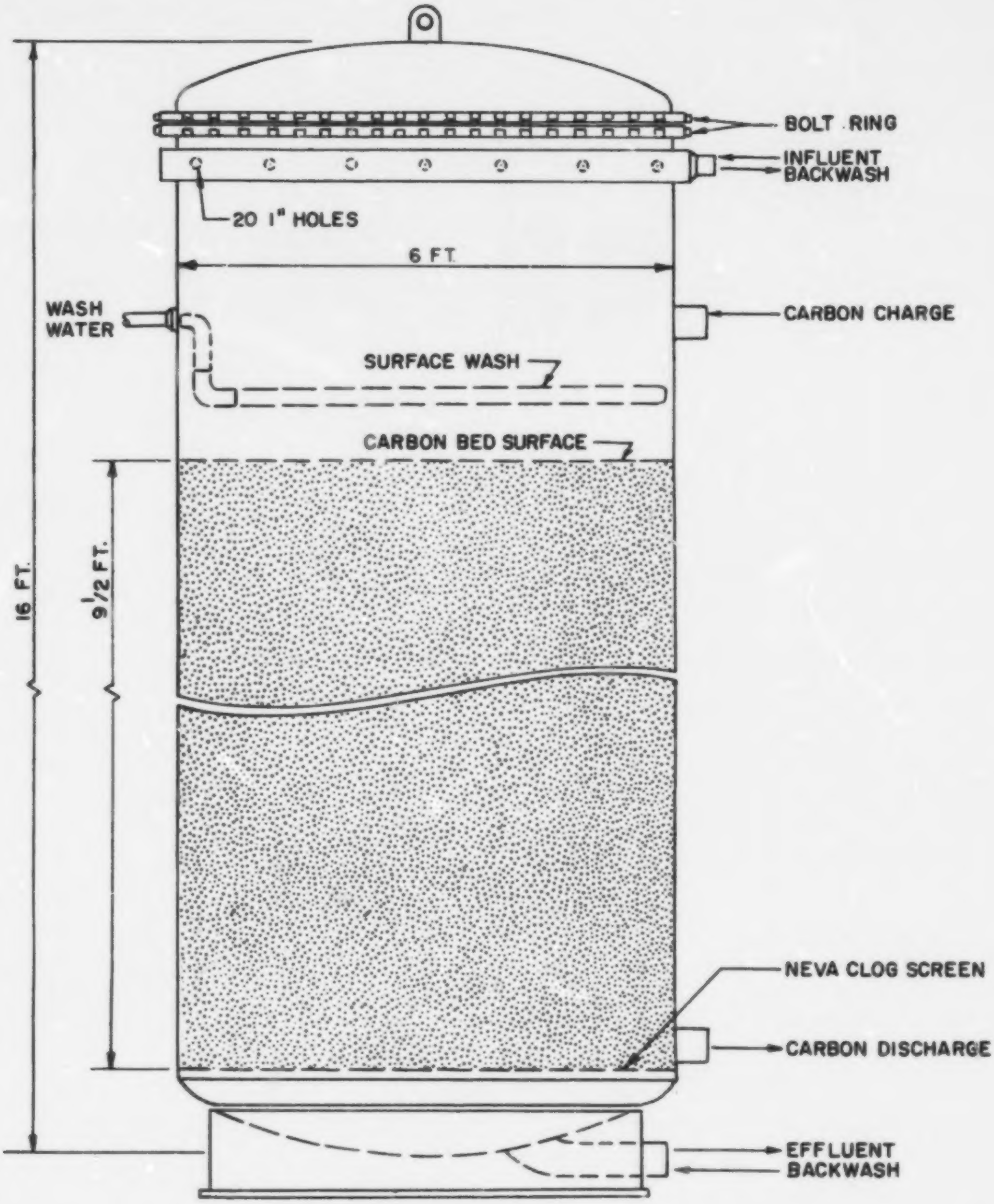

BOLT RING
INFLUENT
BACKWASH
20 1" HOLES
6 FT.
WASH WATER
CARBON CHARGE
SURFACE WASH
CARBON BED SURFACE
16 FT.
9 1/2 FT.
NEVA CLOG SCREEN
CARBON DISCHARGE
EFFLUENT
BACKWASH

FIGURE 5-1 – PRESSURIZED CONTACTOR I

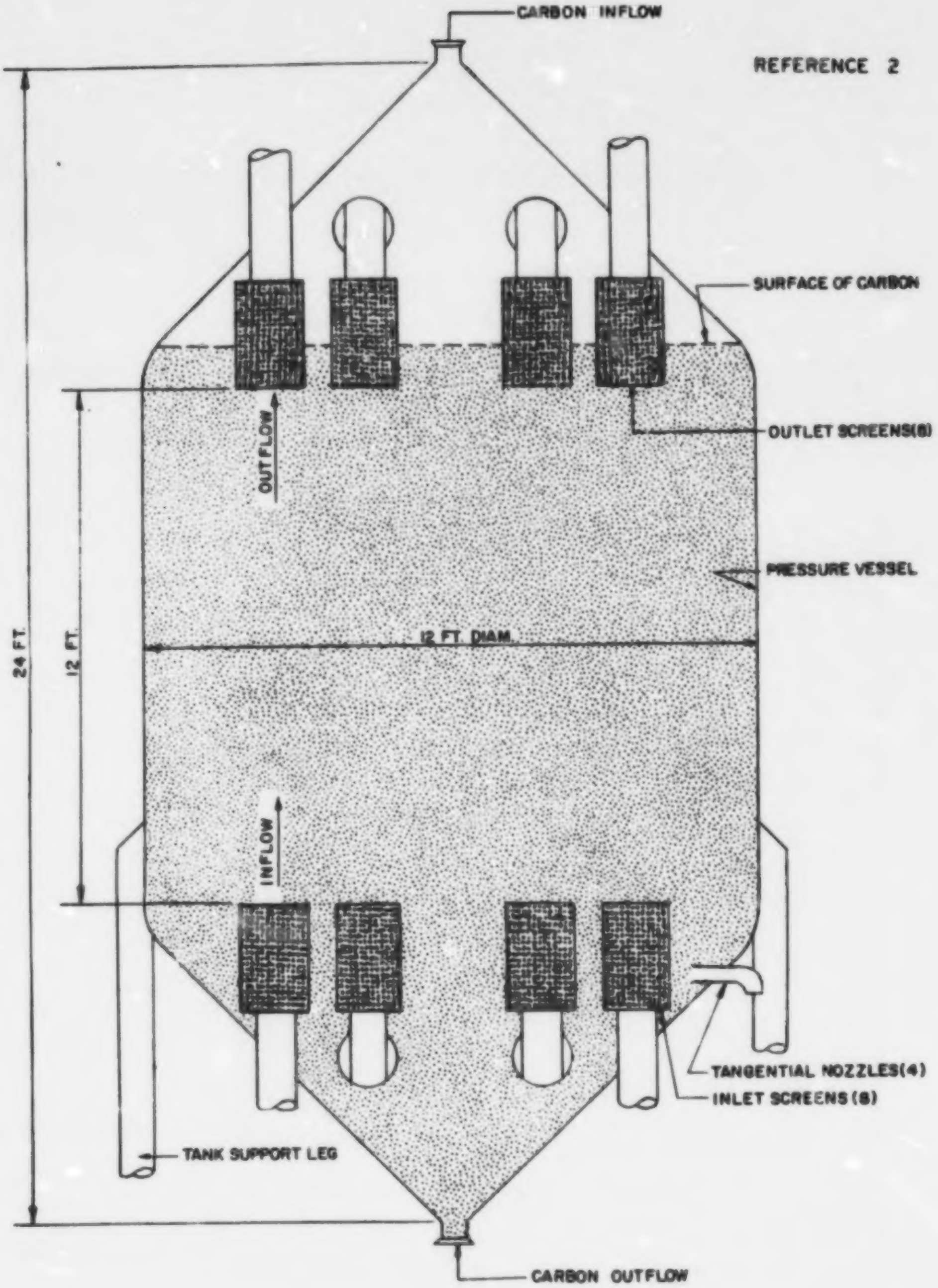

CARBON INFLOW
REFERENCE 2
SURFACE OF CARBON
OUTLET SCREENS(8)
OUTFLOW
PRESSURE VESSEL
12 FT. DIAM.
24 FT.
12 FT.
INFLOW
TANGENTIAL NOZZLES(4)
INLET SCREENS (8)
TANK SUPPORT LEG
CARBON OUTFLOW

FIGURE 5-2–PRESSURIZED CONTACTOR II

REFERENCE 3

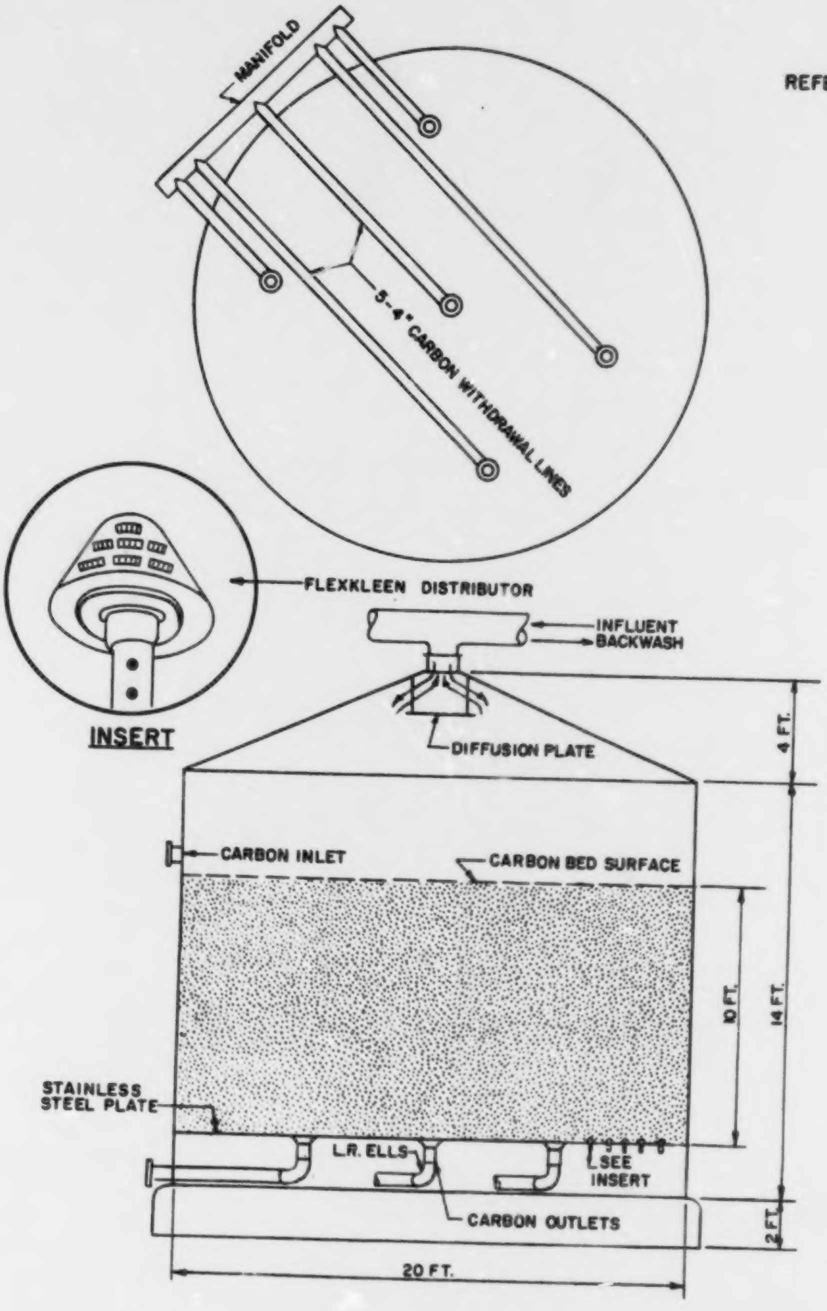

MANIFOLD
5-4" CARBON WITHDRAWAL LINES
FLEXKLEEN DISTRIBUTOR
INSERT
INFLUENT
BACKWASH
DIFFUSION PLATE
4 FT.
CARBON INLET
CARBON BED SURFACE
10 FT.
14 FT.
STAINLESS STEEL PLATE
L.R. ELLS
SEE INSERT
CARBON OUTLETS
2 FT.
20 FT.

FIGURE 5-3—PRESSURIZED CONTACTOR III

REFERENCE 4

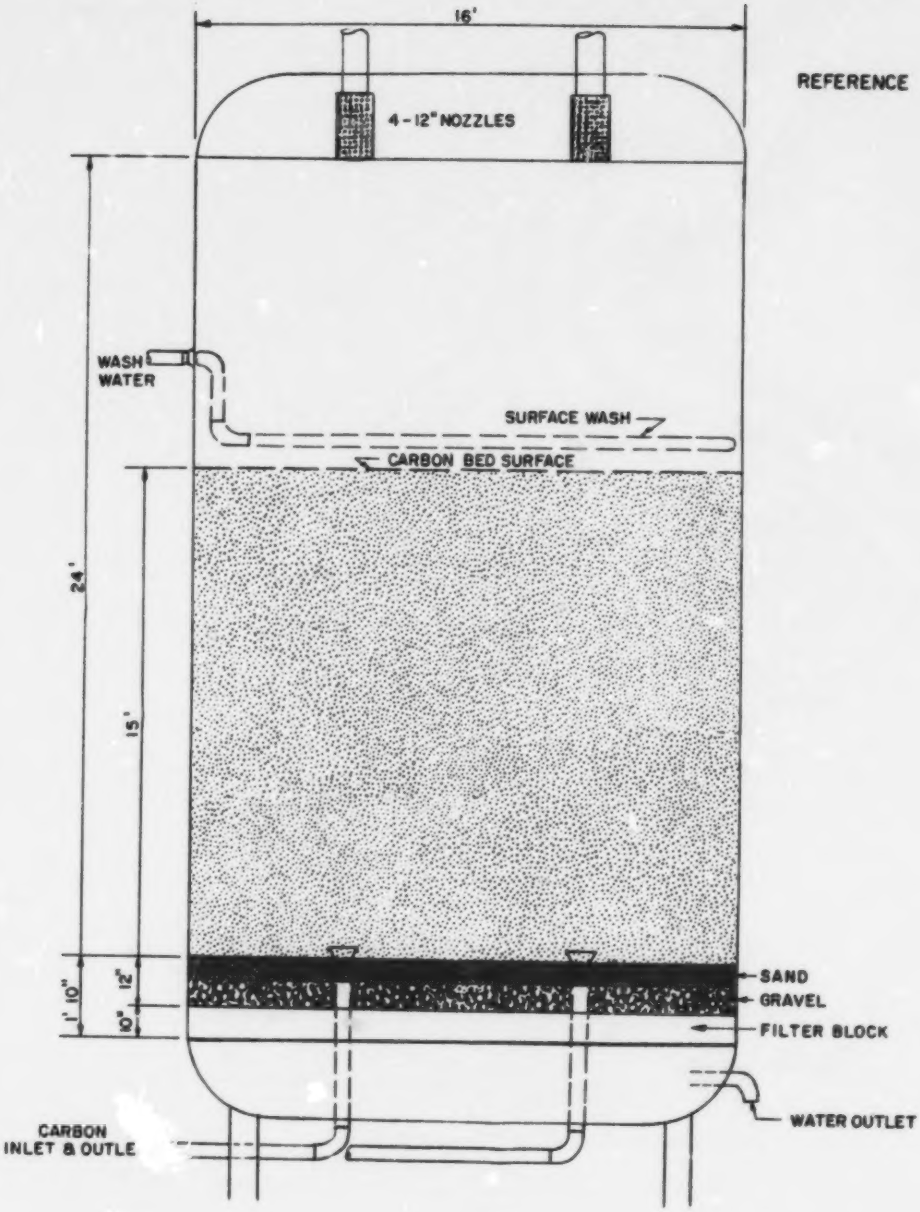

16'
4 - 12" NOZZLES
WASH WATER
SURFACE WASH
CARBON BED SURFACE
24'
15'
1' 10"
12"
10"
SAND
GRAVEL
FILTER BLOCK
WATER OUTLET
CARBON INLET & OUTLE

FIGURE 5-4–PRESSURIZED CONTACTOR IV

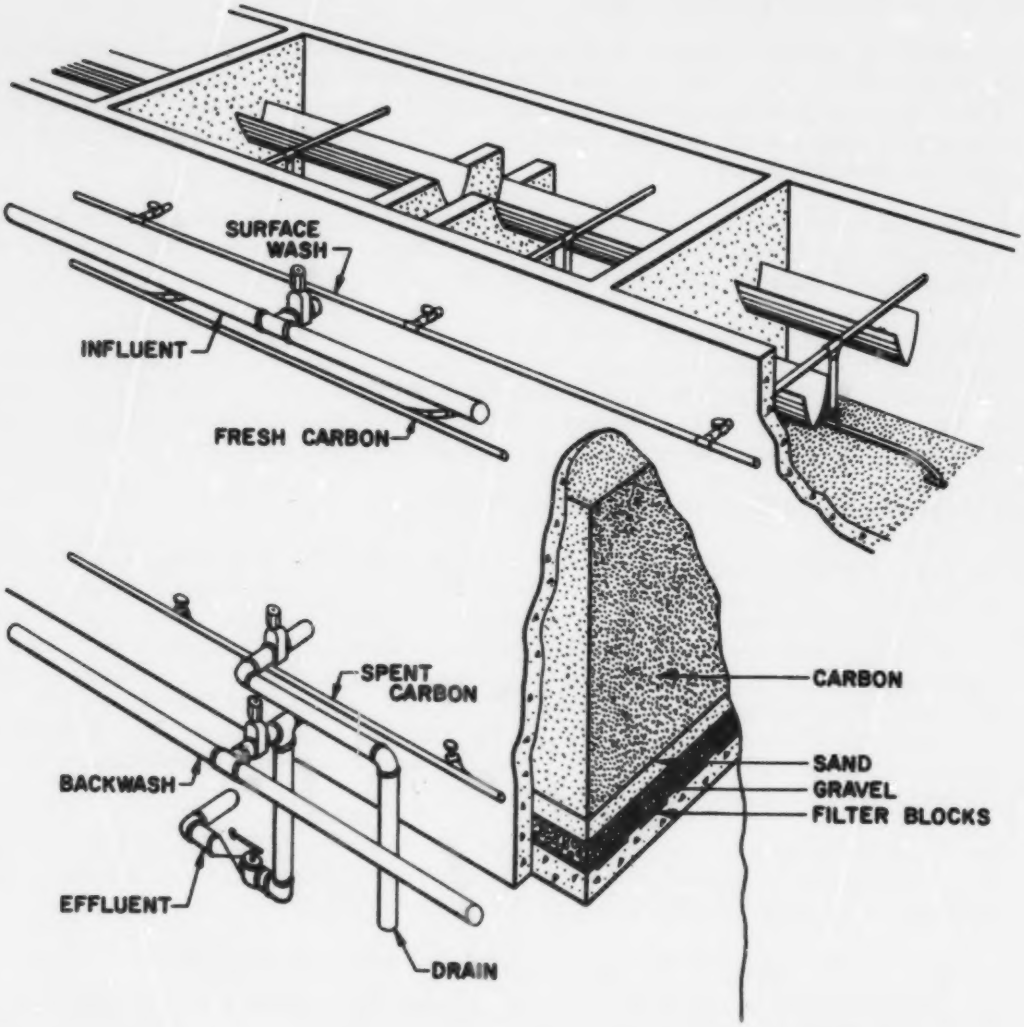

SURFACE WASH
INFLUENT
FRESH CARBON
SPENT CARBON
BACKWASH
EFFLUENT
DRAIN
CARBON
SAND
GRAVEL
FILTER BLOCKS

FIGURE 5-5–GRAVITY CONTACTOR

time. The gravity contactors can be designed using existing sand filter technology, with the additional requirement for carbon withdrawal noted above. The EPA Process Design Manual for Suspended Solids Removal should be consulted regarding filtration technology.

A minimum bed depth to diameter ratio (L/D) of 1 has been suggested to assure good distribution and adequate protection against back mixing. Deeper beds (L/D greater than 1) are susceptible to higher pressure drops.

Corrosion in carbon treatment systems presents some special problems for the designer. Activated carbon is a highly reactive material, especially in the presence of oxygen and water. Contacting vessels are relatively easy to protect through the use of special coating materials. Piping, pumps, and valves are more vulnerable, however, and thus deserve special attention from the designer.

Carbon contacting vessels have so far been constructed of materials that resist attack by the wastewater to be treated. In the case of municipal wastes, the contactors could be fabricated from carbon steel and coated with a lining to resist corrosion, or be formed of concrete.

The selection and method of application of the corrosion protective lining are both important. The corrosion pits reported at Pomona and Lake Tahoe were more likely caused by imperfect application of the coating material than by failure of the coating itself. Typical coating materials range from a painted coal tar epoxy to laminated rubber linings. Some of the newer polyethylene coatings are being tested for this application. See also Table 6-1.

5.2 Regeneration of Spent Granular Activated Carbon

To make granular activated carbon economically feasible for wastewater treatment, the spent carbon must be regenerated and reused. When a carbon column has been operated for some time, the quality of its product water deteriorates gradually until it passes some predetermined limit beyond which it is no longer acceptable. The carbon must then be regenerated. When the lead contactor (assuming a multi-stage configuration) is taken offstream, the usual practice is for the number two contactor to become the new lead contactor. All additional contactors, if any more are used, move up one place in the series. A spare contactor containing virgin and/or regenerated carbon is inserted into the last position in series. See also Section 5-9.

The thermal regeneration of carbon is presently the only feasible procedure for destroying adsorbed organics. Thus maximum effort has been concentrated on optimization of thermal regeneration techniques, using a reducing atmosphere of flue gas and steam.

A typical basic sequence for the thermal regeneration of carbon is as follows:

a. The granular carbon is hydraulically transported (pumped) in a water slurry to the regeneration station for dewatering.

b. After dewatering, the carbon is fed to a furnace (usually of the multi-hearth type) and heated to 1500°F – 1700°F in a controlled atmosphere which volatilizes and oxidizes the adsorbed impurities.

c. The hot regenerated carbon is quenched in water.

d. The cooled regenerated carbon is again hydraulically transported to the adsorption equipment or to storage.

The thermal regeneration process itself involves three steps:

a. Drying

b. Baking (pyrolysis of adsorbates), and

c. Activating (oxidation of the residue from the adsorbate).

The regeneration process itself requires 30 minutes: the first 15 minutes is a drying period during which the water retained in the carbon pores is evaporated, a 5 minute period during which the adsorbed material is pyrolyzed and the volatile portions thereof are driven off; and a 10-minute period during which the adsorbed material is oxidized and the granular carbon reactivated.

As a contactor is removed from service for regeneration, the spent carbon is usually hydraulically transported to a drain bin. The drained carbon is dried during the first step in a furnace which heats the carbon up to 212°F (for this phase of the regeneration). During baking, the temperature increases from 212°F to 1500°F, by which time adsorbed organics are thoroughly carbonized. This is accompanied by evolution of gases and by the formation of a carbon residue in the micropores of the activated carbon. The objective of this activating step is to oxidize the carbon residue with minimum resultant damage to the basic pore structure, consequently effecting maximum restoration of the original properties of the carbon. The activating gas temperature during this step is about 1700°F, while the carbon temperatures range from 1500°F to 1650°F. Flue gas supplemented by varying amounts of additional steam produces the desired atmosphere. Laboratory experiments indicate that the most important phase of the regeneration process is that of activation, with the critical parameters being carbon temperature, duration of activation, and steam or carbon dioxide concentration in the activating gas mixture. Since most commercial installations use direct-fired multiple hearth furnaces for regeneration, the combustion of natural gas with air provides the required heat, while carbon dioxide, oxygen and steam, as part of the products of combustion, are the activating agents. Extra steam at approximately one pound per pound of product regenerated is supplied. This requires some steam generating equipment and a boiler feedwater treatment system.

For regeneration processes utilizing multiple hearth furnaces, the over-all carbon losses usually vary from 5% to 10% per regeneration cycle. As stated before, the relatively high cost of granular activated carbon (24¢ to 30¢ per pound) makes it economically necessary to regenerate and reuse the carbon. If a 5% loss of carbon per regeneration cycle is assumed, then most of the carbon originally in use will have been replaced after 20 cycles and the bulk or aggregate properties of the mix will have approached a constant value.

Multiple hearth furnaces used for regenerating carbon should consider the BSP recommendation that the hearth area contain one square foot per 100 lbs of carbon to be regenerated per 24 hours. A slight oversizing of the furnace beyond this provides for future expansion of a treatment plant at very low cost.

The operating cost of the furnace can be developed by assuming a fuel requirement of 3200 BTU and one pound of steam per pound of carbon. The energy required to generate the steam will be approximately 1250 BTU per pound.

The rate at which the carbon in a single contactor is exhausted determines the minimum rate at which this same carbon must be regenerated (in order that it might be available for use again as a spare contactor). The furnace must be oversized by a factor of two or more so that the design regeneration rate exceeds the exhaustion rate by a safe margin.

The regeneration process may be monitored by reducing the apparent density of the carbon back to its virgin value. Larger apparent densities than the virgin value indicate an incomplete regeneration of the carbon and smaller densities are indicative of burning of the carbon.

Laboratory analyses can confirm the regeneration of the adsorptive capacity of the carbon by measuring the effective surface area of the carbon. Two measurements that may be correlated with the surface area are the iodine and molasses adsorption tests. The iodine number is a measure of the total surface area with pore sizes smaller than 10Å diameter. The molasses number is a measure of the pore sizes which are larger than 28Å. Methods for conducting and evaluating these tests are contained in reports by Juhola & Tepper(5) and Culp and Culp(6).

5.3 Air Pollution Control during Activated Carbon Regeneration

The hot gases discharged from the regeneration furnace contain both fine carbon particulates and odorous materials visible as smoke. Since the wet spent carbon enters the top of the furnace near the exit point for the exhaust gases, some of the more volatile adsorbate is removed from the carbon and carried into the atmosphere without being completely oxidized. Both this smoke and the carbon particulates present air pollution problems if left uncontrolled. Therefore, it is imperative that air pollution control equipment be included in the design of the carbon regeneration furnace.

Systems are available and in use which essentially include an afterburner, for removal of smoke and odors, and a wet scrubber or bag filter, for removal of particulates. These are designed as integral parts of the furnace. The furnace will thus probably satisfy local air quality standards, however, the local air pollution control agency should be consulted in any case. It is the task of that agency to judge whether or not their standards are met and to approve the final design of the apparatus.

5.4 Carbon Transport

In early plants, transport of carbon was by mechanical means such as conveyors. However, recent installations have successfully utilized hydraulic systems to pump the granular activated carbon in a water medium since movement of liquids in pipe lines is inherently easier than transport of solids by mechanical means. The hydraulic transport of carbon is accomplished by pumping the mixture at a high enough velocity to create sufficient turbulence in the pipeline to prevent the solid particles from settling and collecting along the bottom of the pipe.

Investigations by the Pittsburgh Activated Carbon Company (now the Calgon Corporation)(7) indicate that a minimum ratio of 2.3 pounds of water per pound of carbon, or 0.28 gallons of water per pound of carbon, and a minimum linear velocity of 2.5 ft/sec are required for transporting carbon-water slurries. This velocity is sufficient to sustain slurry transport of 12 x 40 mesh activated carbon at a 20%-30% solids concentration. Since the settling of the carbon out of the mixture is a function of particle size, particle density, and slurry concentration among other things, the 2.5 ft/sec velocity is only an approximation. It is recommended that a water-carbon ratio of 4 pounds of water per pound of carbon (0.5 gallons water per pound of carbon) be used for transport design.

Linear velocities above the minimum value of about 2.5 ft/sec (preferably in the range of 3 to 4 ft/sec) are considered best for keeping carbon in suspension in both horizontal and vertical lines; operation at higher velocities is possible if pressure drop limitations are not critical, but such operation may result in higher attrition loss of the carbon. To minimize abrasive pipe wear, to control mechanical attrition of particles during transport, and to keep pressure drops at a reasonable level, the velocity of the slurry should not exceed 10 ft/sec. Within these constraints of velocity and slurry composition the pressure drop for slurry transport of granular activated carbon approximates the pressure drop for plain water.

Pilot plant tests(8) indicate that after an initial higher rate, the rate of attrition for activated carbon in moving water slurries is approximately constant for any given velocity, reaching an approximate value of 0.12% fines generated per exhaustion-regeneration cycle. This continual deterioration of the carbon with cyclic operation has been reported to be independent of the velocity of the slurry (within the range recommended previously – 2.5 to 10 ft/sec). Losses of carbon by attrition in hydraulic handling are not related to the type of pump (diaphragm or certrifugal) used.

In most installations, the spent carbon is transported in excess water, and as much of this water as possible must be removed prior to feeding this material to the regeneration equipment. Tests have indicated that dewatering of the spent carbon slurry can be successfully accomplished mechanically (screens, classifiers, forced air) or by gravity. Slurries containing 3 to 4 pounds of water per pound of 12 x 40 mesh carbon have been dewatered to 50-60% moisture (wet basis) by use of vibrating screens. In commercial installations, slurries have been dewatered to 45-55% moisture content by gravity drainage in a tank if sufficient area and time are allowed. Normally 1 hour is sufficient to provide an economically justifiable reduction of the moisture content.

5.5 Backwash

The purpose of backwashing is to reduce the resistance to flow by disengaging solids that have been entrapped in the bed. The rate and frequency of backwash is dependent upon the hydraulic loading, the nature and concentration of the suspended solids in the influent to a carbon column, the carbon particle size, and the method of contacting (upflow, downflow). A contactor operating at a hydraulic loading of 7 gpm/sq ft was backwashed daily to counteract excessive pressure drop, but the same contactors were operated at 3.5 gpm/sq ft, with the same solids loading of 10 mg/l, required only backwashing every 2-1/2 days(9).

Backwash frequency may be determined by any of several criteria: buildup of headloss, deterioration of effluent turbidity, or at regular predetermined intervals of time. It may be convenient to arbitrarily backwash beds at 1-day intervals, for example, without regard for headloss or turbidity. These other criteria may only be of interest during periods of shock solids loading when backwash frequency exceeds once per day.

Backwashing normally requires a bed expansion of 30-50%. It is recommended that a backwash flow rate of 15-20 gpm/sq ft be used with the granular carbons of either 8 x 30 mesh or 12 x 40 mesh. Figure 5-6 drawn from manufacturers' brochures shows some bed expansion obtainable for virgin carbon.

Effective removal of the solids accumulated on the surface of the carbon bed is improved by the use of a surface wash utilizing rotating or stationary nozzles for directing high pressure streams of water at the surface of the bed. A surface wash is normally operated only during

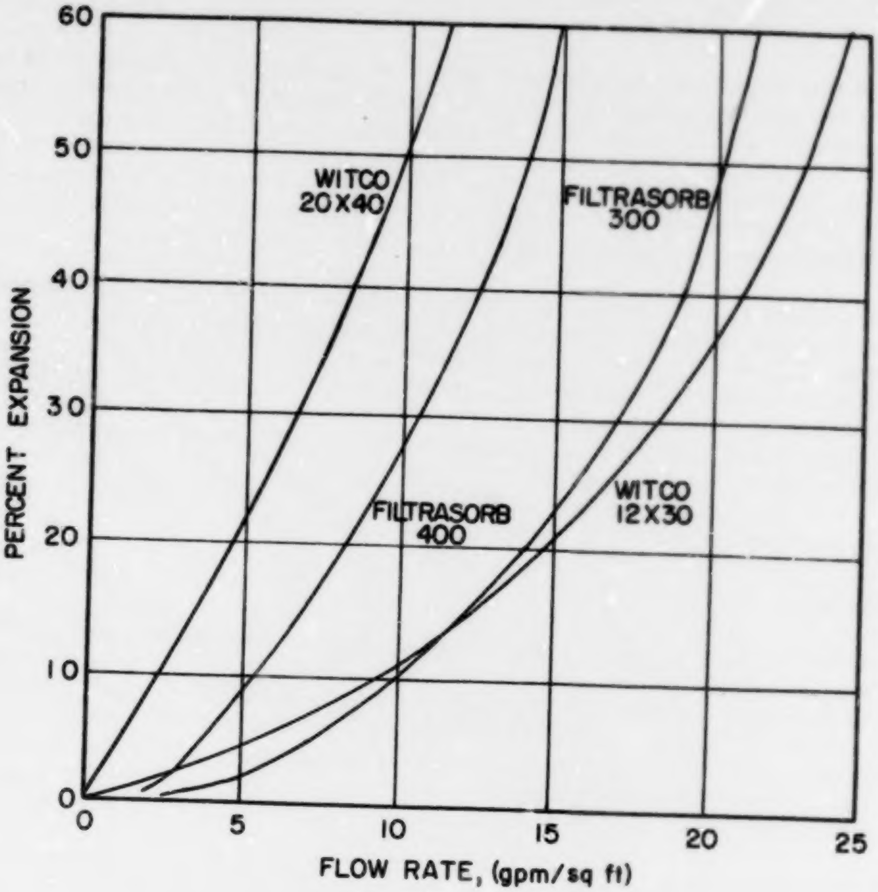


FIGURE 5-6–BED EXPANSION DURING BACKWASH (TEMP. 69°F)

the first few minutes of a 10-15 minute backwash. When backwashing is supplemented by this scouring type of surface wash, the total amount of water to achieve a given degree of bed cleaning should be reduced. As a rule, the total amount of backwash water required should not exceed 5% of the normal throughput. Additionally, the surface wash overcomes bed plugging that may not be alleviated by normal backwash velocities.

The removal of solids trapped in a packed upflow bed may require two steps: first, the bottom surface plugging may have to be relieved by temporarily operating the filter in a downflow mode, and second, the suspended solids entrapped in the middle of the bed may have to be flushed out by additional bed expansion. Air scour, the introduction of an air stream in conjunction with the water backwash, may be necessary to assure proper cleaning of the beds.

The wash water used should be relatively free of suspended solids; if possible, it should be the carbon product water. A second choice for backwash water would be the carbon influent, which may be a particularly attractive source if this water is of good quality.

Backwash water may be effectively disposed of by recirculating it into the primary sedimentation basin or elsewhere near the inlet of the wastewater treatment plant. A typical backwash operation would consist of backwashing each contactor, or at least the lead contactor in a series, on a daily basis. It should be possible to backwash contactors other than the first one in series less frequently than the first one. Backwashing might require about 15 to 45 minutes, depending upon the character of the carbon feed and the hydraulic loading on the carbon column.

5.6 Piping

Carbon is an abrasive material and when hydraulically transported will tend to wear the inside of pipes, particularly in locations where high head loss and excessively turbulent flow are encountered, such as at elbows. Long radius elbows should be used for all bends to reduce wear at these points. Experience with unlined straight pipes, however, has indicated negligible damage to the inside surfaces of the pipes after being in service for several years.

In designing the complete hydraulic system, it is recommended that maximum use be made of manifolding to incrase the overall efficiency and flexibility of the installation. The advantages due to a carefully designed manifold system result in a more compact and economical system with lower initial investment for capital equipment, reduction in spare equipment, and in operating and maintenance costs. The reliability of the installation is improved and the downtime is reduced. The flexibility inherent in manifolding arrangements with necessary valves, pumps, controls, etc. should enable an operator to overcome most emergencies by switching to alternate pipe lines. The piping system should be designed with an eye towards easy flushing after each slurry transport operation. This requires the use of sufficient cleanouts, flushing connections and drains.

Steel pipes have been used satisfactorily in applications where the slurry transport is not continuous. Steel is also advisable when the piping is readily accessible to effect economic repair or replacement. More expensive materials or linings such as rubber, saran, polyvinyl chloride and stainless steel may be justified only under special conditions, e.g., in the industrial sector where corrosive liquids may be encountered.

Valves used in wastewater disposal systems may be classified in several categories, each of which may be further subdivided according to various design options.

Diaphragm (straight way)
Globe
Rotary (ball, butterfly, cone, plug)
Slide, (gate valve, shear gate)
Sphere check
Swing check

In selecting a valve for installation in a slurry transport line, there are four major considerations: the purpose of the valve, its effectiveness in accomplishing functional requirements, the resistance of the valve to the abrasive effects of slurry transport, and the cost.

The globe valve and slide valve, normally used to effect positive shut off of flow in a pipe line are not applicable because they require a positive seating.

The passage of an abrasive slurry through these valve configurations in the open position may wear the seating or perhaps leave carbon granules lodged in the seating grooves, thus preventing positive shutoff.

Preferred valves to assure positive off and on operations are the rotary type such as the ball, cone, and plug valves. These valves should offer no restriction to slurry transport when in the open position. The diaphragm valve, certain variations of which offer limited blockage of the open passage, has a movable element of flexible rubber, leather or some special composition, which will be worn over a period of use and will require replacement.

Both swing type and spherical check valves are suitable for back flow prevention in slurry pumping. Although the seating face against which the closing device rests is susceptible to abrasive wear and the flow is restricted by the configuration of the valve, there is no acceptable substitute that can achieve the same purpose.

Regulation of slurry flow can best be accomplished by either a diaphragm valve or a rotary valve such as the butterfly valve. These valves should have as their only function flow regulation and would not be expected to provide positive flow shutoff. The useful life of the wearing surface or seating face of valves can be extended by the use of rubber lining and stainless steel.

If the carbon slurry piping system is one to two inches in size, the cost of periodically replacing a common valve may be far less than installing a high-priced, specially-lined valve.

5.7 Pumps

The motive force to convey slurries through pipelines can be provided by pumps alone or a combination of pumps and eductors. For the range of slurry concentrations used in existing facilities, either centrifugal pumps or by a combination of centrifugal pumps and eductors have proven satisfactory. If carbon is to be transported at higher slurry concentrations, consideration should be given to using diaphragm slurry pumps or double-acting positive displacement pumps of the simplex, duplex and triplex variety.

For the pumping of a 25% granular carbon slurry, centrifugal pumps should have extra large suction inlets, a non-clogging type of impeller, and an extra large packing box with seal to protect the shaft from wear. Preferred materials of construction include 316 stainless steel, silicon iron or rubber lining; this is true especially for those components in contact with the abrasive slurry. Field experience indicates, however, that there is a tendency to pull the rubber linings out.

The eductor serves the two-fold purpose of mixing carbon and water and of accelerating the transport fluid. It must, of course, have a pump associated with it to assure pressure and flow. In such an application, the pump may be selected as though it were intended for pumping clean water.

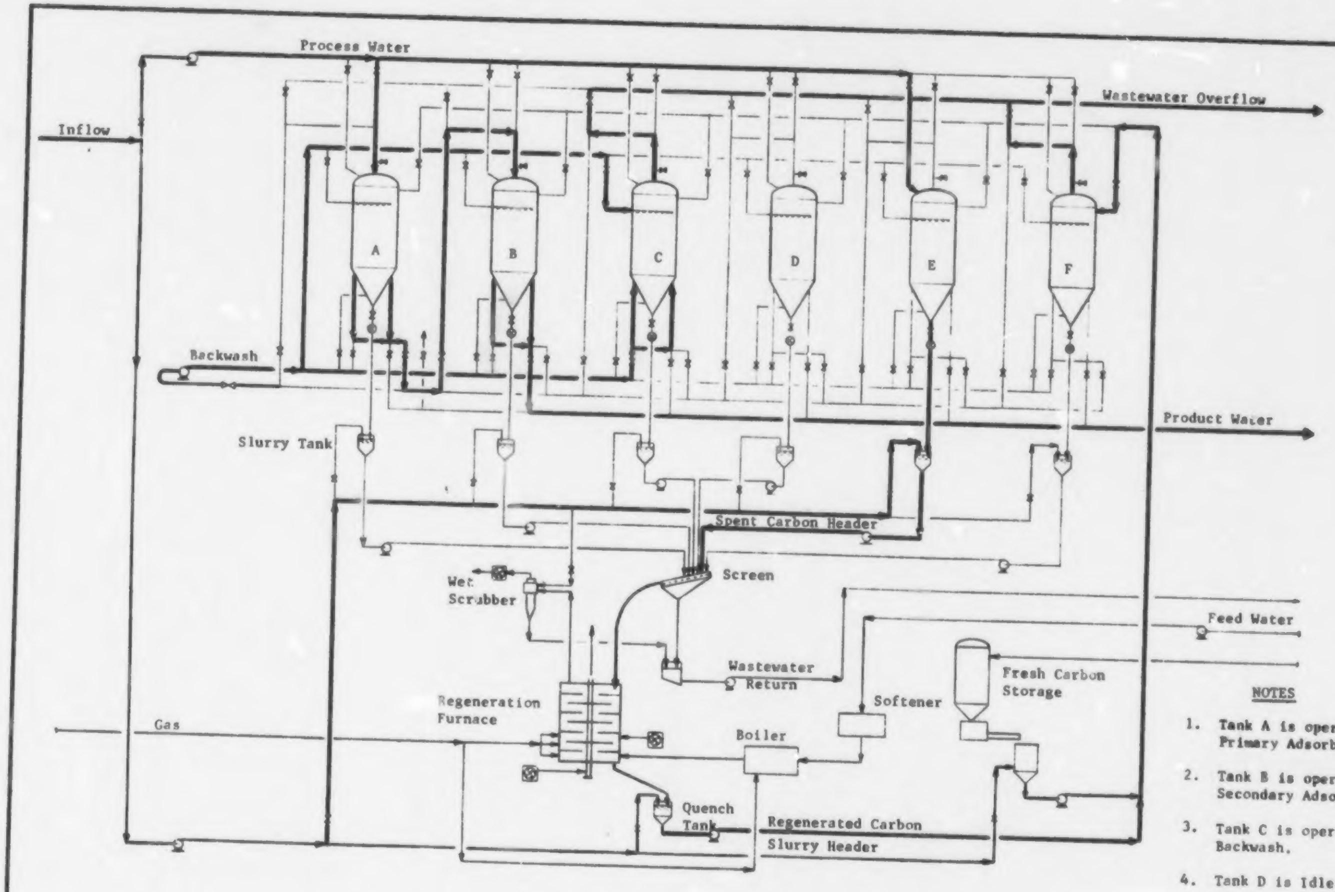
5.8 Control System

Automatic operation of carbon-contacting systems is accomplished by standard equipment which is well developed and reliable. Although automatic control is quite feasible, it is frequently not required because of the extended lengths of time between operations of the equipment; valves serving separate carbon vessels are usually operated only during withdrawal and replacement of carbon for regeneration, except for occasional flow reversals. Since this operation occurs about once every one to two months, it is best to operate the valve manually, with careful observation and attendance. In downflow arrangements in which the carbon beds act as filters in addition to providing adsorption sites, the control and operation of these systems can become somewhat complex and subject to failures resulting in delays and even complete plant shutdown. Basically a surface-type filter, the downflow carbon contactor is vulnerable to all of the problems of this type of filter. Any severe pretreatment upset resulting in a sudden increase in suspended solid may completely blind or clog the surface of the bed, requiring backwashing to restore service.

5.9 A Typical Plant Operation

So far, we have discussed all of the component parts of a carbon treatment plant and several possible flow configurations. However, there are some important aspects of a carbon plant which cannot be adequately described in the above format. The arrangement of the carbon contactors in a workable system requires a considerable design effort in the area of internal piping, valves, pumps, and intermediate tanks. These elements are vital in providing the flexibility which characterizes an efficient and economical carbon treatment system. Therefore, in this section we shall illustrate one particular integrated plant design complete with piping, valves, pumps, etc., and attempt to demonstrate how plant flexibility may be obtained.

Figure 5-7 illustrates one reasonable design for a plant with 2-stage contactors. This design in fact provides 3 parallel 2-stage systems in an arrangement intended to provide almost uninterrupted operation by rotation of those 3 systems. Each of the 3 parallel systems can be shifted from the service (treatment) mode to the backwash mode and back again, or to the regeneration mode and back again. At any given time, two 2-stage systems are in service, although one of these can be taken out of service to be backwashed, and one is being regenerated. In Figure 5-7, contactors A and B are in service, C and D are momentarily out of service so that C can be backwashed, and E and F are in the regeneration mode. E is being emptied of spent carbon and F is being filled with regenerated carbon. E has just been taken out of service to be regenerated, while F will be ready to replace either A or C when one of them is exhausted.


Process Water
Inflow
Wastewater Overflow
A
B
C
D
E
F
Backwash
Product Water
Slurry Tank
Spent Carbon Header
Screen
Wet Scrubber
Feed Water
Wastewater Return
Fresh Carbon Storage
Softener
Regeneration Furnace
Gas
Boiler
Quench Tank
Regenerated Carbon
Slurry Header

NOTES

1. Tank A is operating as Primary Adsorber.
2. Tank B is operating as Secondary Adsorber.
3. Tank C is operating on Backwash.
4. Tank D is Idle.
5. Tank E is operating on a Cycle to Remove Carbon.
6. Tank F is operating on a Cycle to Refill with Activated Carbon.

FIGURE 5-7—PROCESS FLOW DIAGRAM

If an influent surge should develop, blinding A and C with solids, then the plant would be temporarily shut down until either A or C had been backwashed. In the event of a surge in organic loading, then A and C might be prematurely exhausted, and could be replaced by B and D respectively.

All of these contactor rearrangements are possible through appropriate manipulation of valves. The process water header at the top of the diagram can serve any of the 6 contactors. In the situation shown, only the valve atop contactor A is open. The product water header can transfer the effluent of any one contactor to the inlet of any other contactor. A is shown feeding B. Any combination of contactors can be backwashed through the backwash header. C is shown being backwashed. Spent carbon is shown being drained from E through the small slurrying tank located directly beneath (in the diagram) each contactor. The spent carbon is then transported to a dewatering screen and then to the regeneration furnace. Regenerated carbon is drawn from the furnace into the quench tank, and then transported in slurry form through its own header. F is shown receiving regenerated carbon in this fashion.

Obviously this configuration in Figure 5-7 represents only one possible arrangement for the 6-vessel system. Instead of 3 parallel 2-stage contactors, any number of the 6 vessels could be operated in series or in parallel as circumstances required. The spent carbon dewatering system is somewhat idealized by comparison with Figures 3-1, 3-2, and 3-3.

Most of the valving operations suggested here (referring to Figure 5-7) need not be automated for the simple reason that they are not performed frequently enough to warrant it. Manual operation is sufficient in most instances, although care must be taken to open and close the proper valves in proper sequence.

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CHAPTER 6

PHYSICAL–CHEMICAL TREATMENT PLANTS

6.1 General

The basic design parameters used in the design of carbon treatment plants may vary in practice over only a relatively narrow range. Determination of the values of these parameters for a particular wastewater must be accomplished by testing as described in Chapter 7.

Table 6-1 summarizes the design parameters from some of the new carbon plants being designed as well as from older plants. Many of the figures are drawn from preliminary engineering reports and must therefore be regarded as tentative and subject to change. The ranges over which some of these parameters vary are:

Design Parameters

Carbon Requirements:	(tertiary plants)	250–350 lbs of Carbon per MG
	(secondary plants)	500–1800 lbs of Carbon per MG
Hydraulic Loading		2–10 gpm/sq ft
Contact Time (empty bed)		15–40 minutes
Backwash Rate		15–20 gpm/sq ft
Vessel Configuration		One and two stage

6.2 Physical Chemical Treatment Plants Being Built

Most design engineers considering the application of carbon as part of a physical-chemical treatment scheme cite its main attraction to be its ability to produce an effluent very low in dissolved organics. This ability makes it rather easy to meet treatment objectives of 85% BOD removal or more, either through upgrading an existing biological plant or through building an entirely new PCT plant. Table 6-2 is a list of some of those plants which are incorporating physical-chemical treatment. Some of the plants cited above are worthy of further comment.

Rocky River, Ohio(1)

Originally a primary treatment plant, effluent quality standards intended to protect Lake Erie demanded an improved treatment performance by the Rocky River plant. The treatment objective was set at BOD_5=15 mg/l. Restrictive land area forbade the construction of a conventional biological secondary plant, so a PCT plant was designed. The primary facility will be converted into part of the PCT plant, so the influent to the PCT plant will be raw wastewater. The treatment sequence is planned to be: 1. gross solids removal; 2. chemical clarification via ferric chloride and polymer; 3. downflow carbon adsorption; 4. chlorination. No filtration step is provided prior to the carbon treatment, a notable point.

The design (average) flow is 10 MGD, projected for 1980. The peak flow is projected as 20 MGD. Average raw wastewater characteristics (1967) include: suspended solids: 140 mg/l; BOD_5: 110 mg/l; COD: 240 mg/l; total phosphorus: 21 mg/l. The $FeCl_3$ feeder capacity is planned to be 30 mg/l Fe.

The 8 single-stage carbon columns are pressurized downflow systems. One column can be backwashed using the effluent volume from the other 7 columns.

Table 6–1

DESIGN SPECIFICATIONS OF SOME PCT PLANTS

(A) Secondary Plants, replacing biological plants

	Rocky River, Ohio	Owosso, Michigan	Garland, Texas	Niagara Falls, New York
Carbon Requirements	500 lbs/MG	600 lbs/MG	1800 lbs/MG	750 lbs/MG
Plant Size	10 MGD	6 MGD	30 MGD	60 MGD
Hydraulic Loading	4.3 gpm/sq ft	6.2 gpm/sq ft	2.4 gpm/sq ft	1.5 gpm/sq ft
Contact Time	26 minutes	36 minutes	30 minutes	40 minutes
Bed Depth	15 ft	30 ft	10 ft	8 ft
Contactor Size	16 ft dia x 25.3 ft	12 ft dia	20 x 47.5 ft	40 x 20 x 18 ft
Carbon Size	8 x 30 mesh	12 x 40 mesh	—	—
Carbon Inventory	736,870 lbs	246,480 lbs	2,600,000 lbs	—
Backwash Rate	15–20 gpm/sq ft	N/A	N/A	—
Surface Wash	stainless steel, rotating spray	N/A	N/A	—
Air Scour	none	N/A	N/A	—
Vessel Type	pressure-downflow	pressure-upflow	gravity-upflow	gravity-downflow
Regeneration Rate	500 lbs/hr	416 lbs/hr	—	—
Furnace*	72 OD 8	54 ID 6	—	—
Corrosion Protection	rubber lining	—	Concrete and stainless steel	concrete
After Burner	yes	—	no	yes
Wet Scrubber	no	—	yes	no

*72 OD 8 means 72" outer diameter and an 8-hearth furnace

Table 6–1 (continued)

DESIGN SPECIFICATIONS OF SOME PCT PLANTS

(B) Tertiary Plants, upgrading biological plants

	Colorado Springs, Colorado	Pomona, California	South Lake Tahoe, California
Carbon Requirements	250 lbs/MG	350 lbs/MG	250 lbs/MG
Plant Size	3 MGD	0.3 MGD	7.5 MGD
Hydraulic Loading	5 gpm/ sq ft	7 gpm/ sq ft	6.2 gpm/sq ft
Contact Time	30 minutes	40 minutes	17 minutes
Bed Depth	20 ft	38 ft	14 ft
Contactor Size	20 ft dia x 20 ft	6 ft dia x 16 ft	12 ft dia x 14 ft
Carbon Size	8 x 30 mesh	12 x 40 mesh	8 x 30 mesh
Carbon Inventory	250,000 lbs	—	500,000 lbs
Backwash Rate	20 gpm/sq ft	12 gpm/sq ft	N/A
Surface Wash	—	—	N/A
Air Scour	—	—	N/A
Vessel Type	pressure-downflow	pressure-downflow	pressure-upflow
Regeneration Rate	75 lbs/hr	110/hr	250 lbs/hr
Furnace*	30 ID 6	30 ID 6	54 ID 6
Corrosion Protection	—	coal tar epoxy	coal tar epoxy
After Burner	yes	yes	available
Wet Scrubber	—	yes	yes

*30 ID 6 means 30" inner diameter and a 6-hearth furnace

Table 6–2

PHYSICAL–CHEMICAL TREATMENT PLANTS BEING BUILT

SITE	CONSULTANTS	PLANT CAPACITY (MGD)	STATUS
Rocky River, Ohio	Willard Schade & Assoc.	10	Bids Taken
Cleveland, Ohio	Engineering-Science, Inc.	10(b)	Design
Fitchburg, Mass.	Camp Dresser & McKee	15	Design
Cortland, N.Y.	Stearns & Wheler	10	Planned
Niagara Falls, N.Y.	Camp Dresser & McKee	60	Design
Garland, Texas	Forrest & Cotton, Inc.	30(b)	Design
Owosso, Michigan	Ayres, Lewis, Norris & May, Inc.	6	Design
Piscataway, Md.	Roy F. Weston	5	Construction
Colorado Springs, Colo. (a)	Arthur B. Chafet & Assoc.	3	Operational

(a) Tertiary treatment following trickling filter.

(b) First of several modules: ultimate plant sizes are projected to be–

Cleveland	80 MGD
Garland	90 MGD

Owosso, Michigan(2)

A new plant is being built to accommodate several adjacent towns in the Owosso area. The existing primary plant must be upgraded as well as expanded, particularly in the area of phosphorus and nitrogen removal. The treatment objectives now will require a BOD_5 of 7 mg/l during low river stages, and 85% removal of phosphorus in order to safeguard the Shiawassee River. The proposed treatment sequence is: 1. gross solids removal; 2. chemical clarification via lime and alum; 3. pressurized deep bed filtration; 4. upflow carbon adsorption; 5. breakpoint chlorination of ammonia (projected); 6. removal of excess chlorine and an organic polishing in downflow carbon columns.

The design (average) flow is 6 MGD, with a projected peak flow of 12 MGD. Average raw wastewater characteristics include: suspended solids: 180 mg/l; BOD_5: 90 mg/l; COD: 300 mg/l.

The carbon columns will include 6 parallel trains of 2-stage contactors, and will be pressurized upflow systems.

Garland, Texas(3)

The expansion of the Duck Creek plant in Garland (suburban Dallas) will incorporate PCT largely because of the influx of industrial wastes into the municipal waste stream. The treatment sequence will feature: 1. gross solids removal; 2. filtration; 3. gravity expanded bed upflow carbon adsorption; 4. chlorination. Initially, the existing trickling filter plant will be operated in parallel with the PCT plant.

The PCT design flow will initially be 22.5 MGD. The total plant (including trickling filter) will be 30 MGD. This is an example of a modular approach to plant design and construction. Ultimately the plant capacity (entirely PCT) will go up to 90 MGD. Average raw wastewater characteristics include: suspended solids: 230 mg/l; BOD_5: 260 mg/l; COD: 540 mg/l; filtered COD: 240 mg/l.

The carbon contactors will be 10 rectangular concrete-walled single-stage beds operating upflow under gravity. The projected carbon requirement here is 1800 lbs/MG, a conservative figure which presumes little or no biological treatment on the carbon.

Niagara Falls, New York(4)

Maintaining the quality of the Niagara River, which discharges into Lake Ontario, was the main reason for construction of a PCT plant at Niagara Falls. The high industrial waste load at Niagara Falls would not be readily amenable to biological treatment. The process sequence includes: 1. gross solids removal; 2. chemical clarification; 3. sedimentation; 4. gravity downflow carbon adsorption; 5. chlorination.

The design (average) flow will be 60 MGD. Raw wastewater characteristics include: suspended solids: 280 mg/l; BOD_5: 50 mg/l; COD: 150 mg/l.

The carbon portion of the plant will be comprised of 32 single-stage gravity downflow contactors.

Colorado Springs, Colorado(5)

The existing trickling filter plant is grossly overloaded (by a factor of 2–3) due to a rapid increase in population and development, and has been upgraded by addition of a tertiary stage. The process train is: 1. trickling filter; 2. chemical clarification via lime; 3. filtration; 4. downflow carbon adsorption. In fact, the raw wastewater entering the plant is so strong that the secondary plant produces what would normally be thought of as raw wastewater quality. Therefore, although the PCT plant is technically a tertiary stage, it is doing the job of a secondary plant. The tertiary plant recently became operational in December of 1970. It is at present treating only a portion of the total flow (3 MGD out of about 40 MGD).

The intent of the tertiary plant was not only to upgrade effluent quality in order to meet state standards, but also to supply cooling water for the municipal power plant.

In 1971, the trickling filter effluent has averaged: BOD_5:130 mg/l; COD: 320 mg/l. Under this loading, the carbon effluent has been running: BOD_5: 29 mg/l; COD: 44 mg/l. The tertiary plant is therefore putting out secondary quality water under heavy influent loadings.

Pomona, California(6)

This is a pilot plant operated by EPA since 1965. It is a 0.3 MGD tertiary treatment plant receiving effluent directly from a good activated sludge plant, without any intermediate clarification or filtration step. Average removals by the carbon beds since 1965 include: suspended solids: 93%; COD: 77%; dissolved COD: 73%; color: 89%. Effluent quality has averaged: suspended solids: 0.6 mg/l; BOD_5: 1 mg/l; COD: 10 mg/l; dissolved COD: 8 mg/l; color: 3 units. Considerable research on carbon regeneration has also been done. The data has been widely published.

The pressurized downflow carbon columns are shown in Figure 6-1. Figure 6-2 shows the regeneration furnace in the right center foreground, the carbon drain bin and vibrator to the right, and the carbon quench tank set partially into the ground to the left of the furnace.

South Lake Tahoe, California(7)

A 7.5 MGD tertiary treatment plant now receives the lime-clarified, filtered discharge from an activated sludge plant. The carbon system is comprised of 6 parallel upflow single-stage contactors. The plant has in the past been operated as both a partially expanded bed and as a packed bed. Spent carbon is removed from the bottom of the bed and fresh carbon is charged at the top. Figure 6-3 shows some piping detail at the top of one of the carbon contactors. The small vessel at the top of the picture contains the carbon to be charged into the contactor. This was originally a 2.5 MGD plant, but was later expanded to 7.5 MGD. The performance of this plant has been widely published by Culp(8).

Wilmington, California(9)

The Watson refinery of the Atlantic Richfield Co. has an operating gravity downflow carbon adsorption plant to treat the refinery wastewater prior to discharge into the Dominguez Channel. During and after periods of rainfall, no plant effluent could be discharged into the city sanitary sewer system because the plant's stormwater and process water flows were collected in a common system. Therefore, the combined flows were impounded prior to treatment and then discharged into the Channel. The stricter effluent quality standards imposed required that an improved treatment system also be installed. The variations in flow due to the combined collection system mitigated against the construction of a biological plant. A PCT plant including activated carbon has been operational since December 1970. The pretreatment steps consist of a variety of processes intended to remove oil from the waste stream, and included flocculation and air flotation.

The design flow is 4.2 MGD and is uniform due to the preceding impoundment basin. The plant is expected to reduce 250 mg/l of COD to no more than 30 mg/l, and suspended solids to virtually nil. The hydraulic loading is 1.7 gpm/sq ft with a contact time of 1 hour. The concrete gravity contactors are 12 x 12 x 26 ft deep, each containing 13 ft of carbon. There are 12 parallel single-stage contactors. Backwashing is once per day.

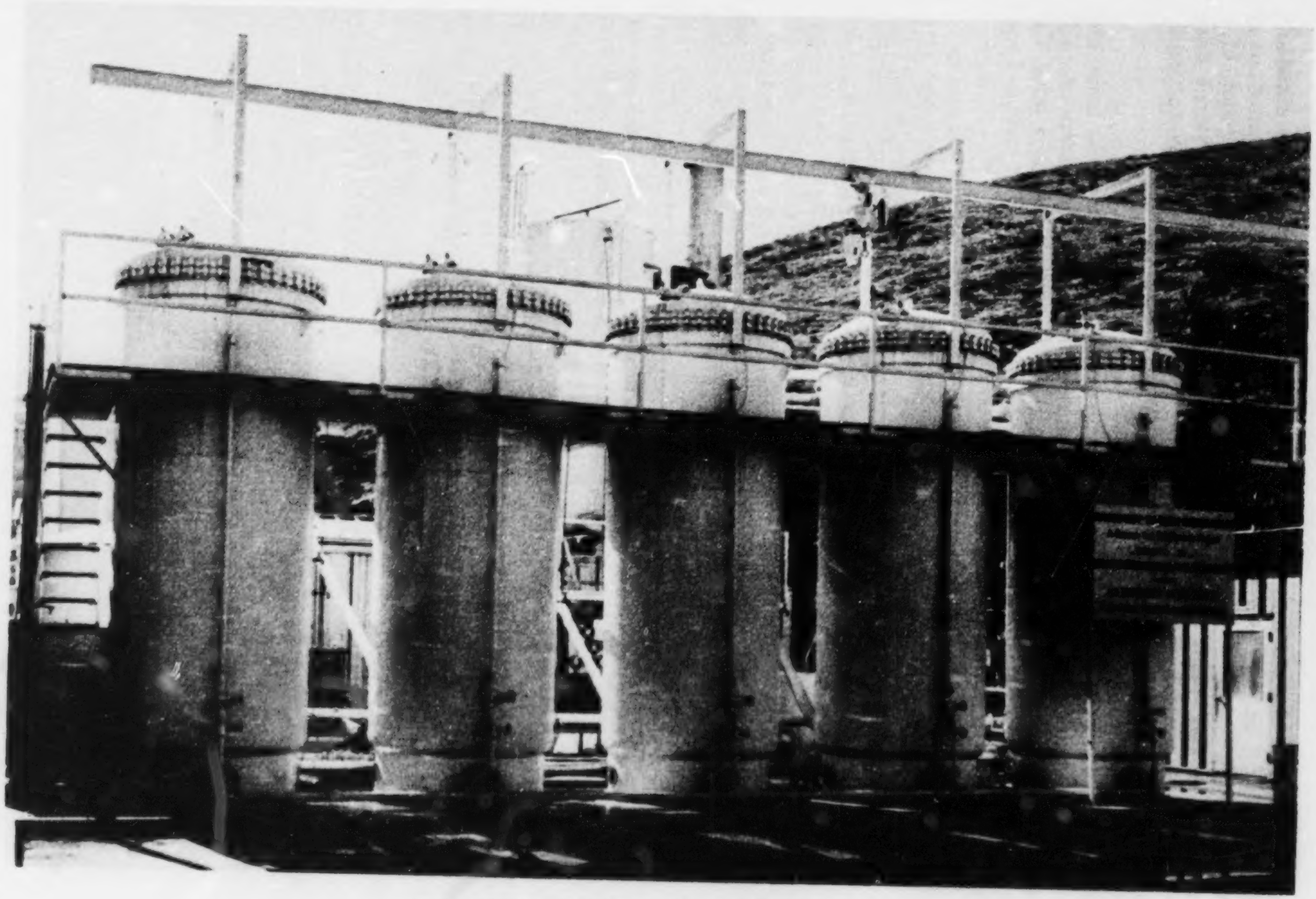

FIGURE 6-1—POMONA CARBON CONTACTORS

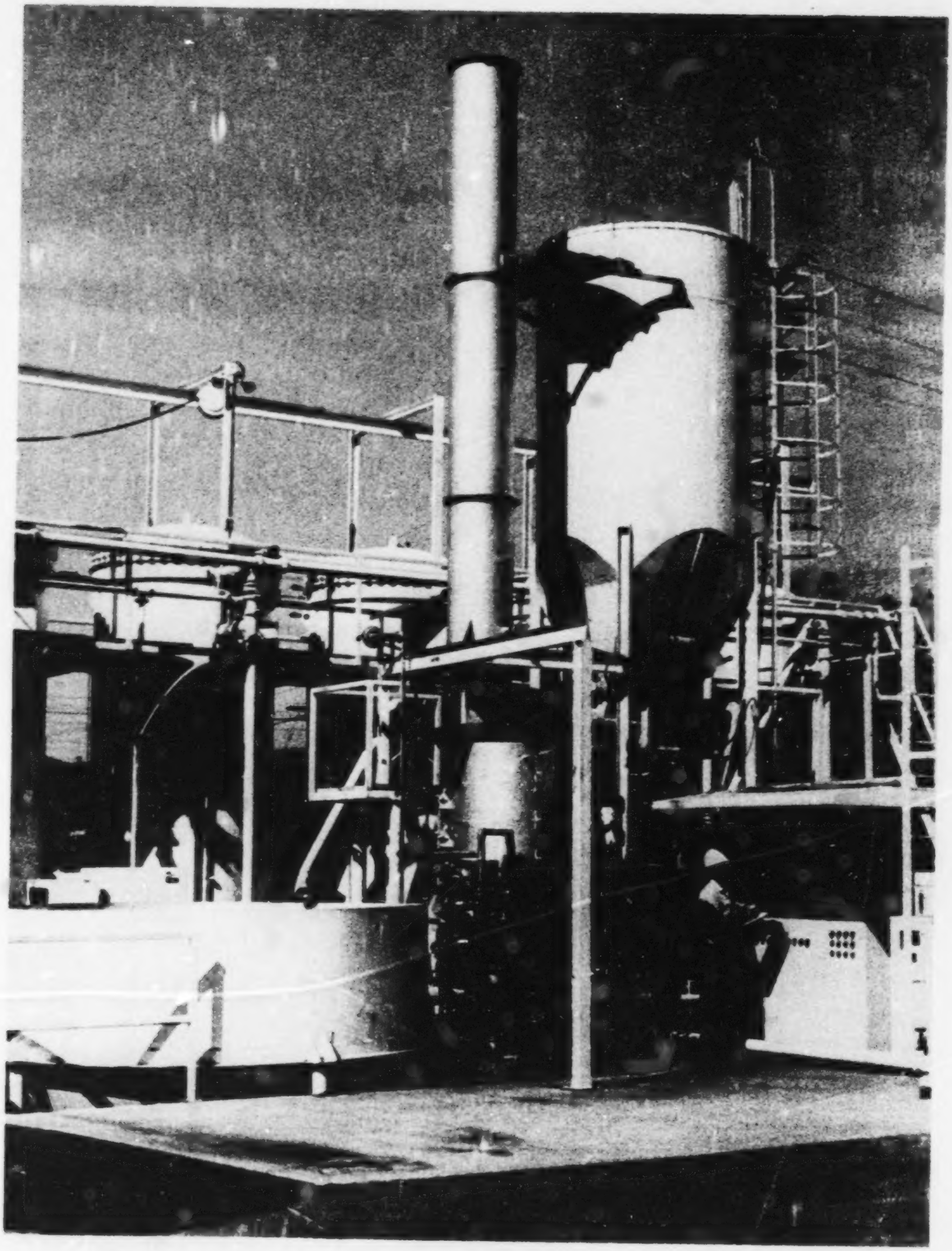

FIGURE 6-2–POMONA REGENERATION SYSTEM

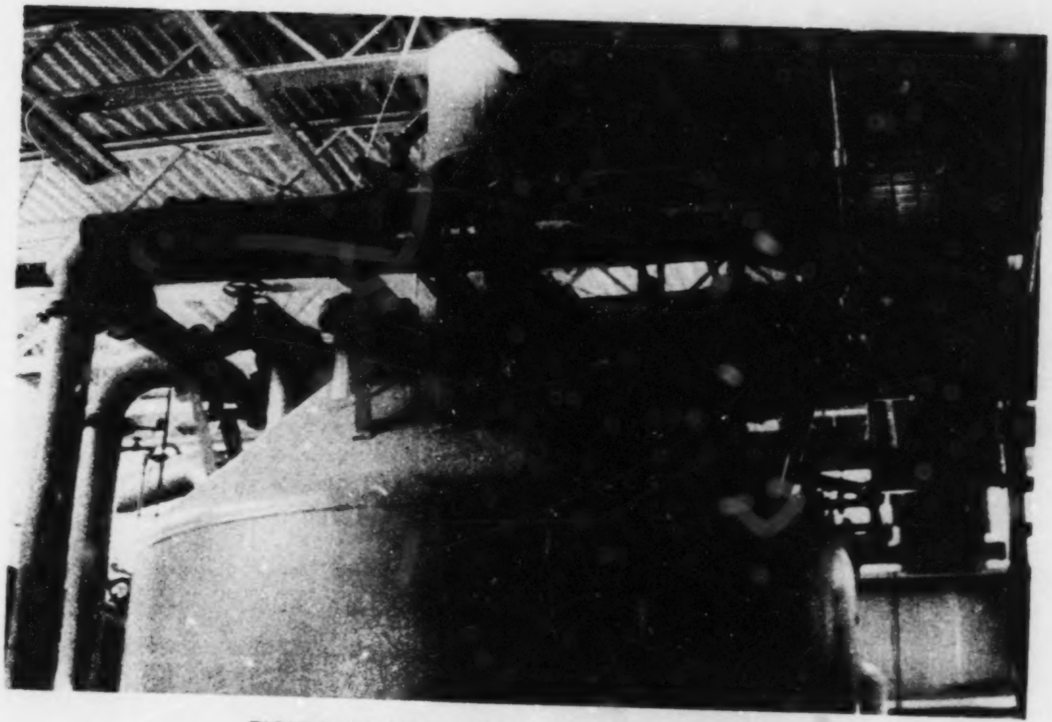

FIGURE 6-3—LAKE TAHOE CARBON CONTACTOR

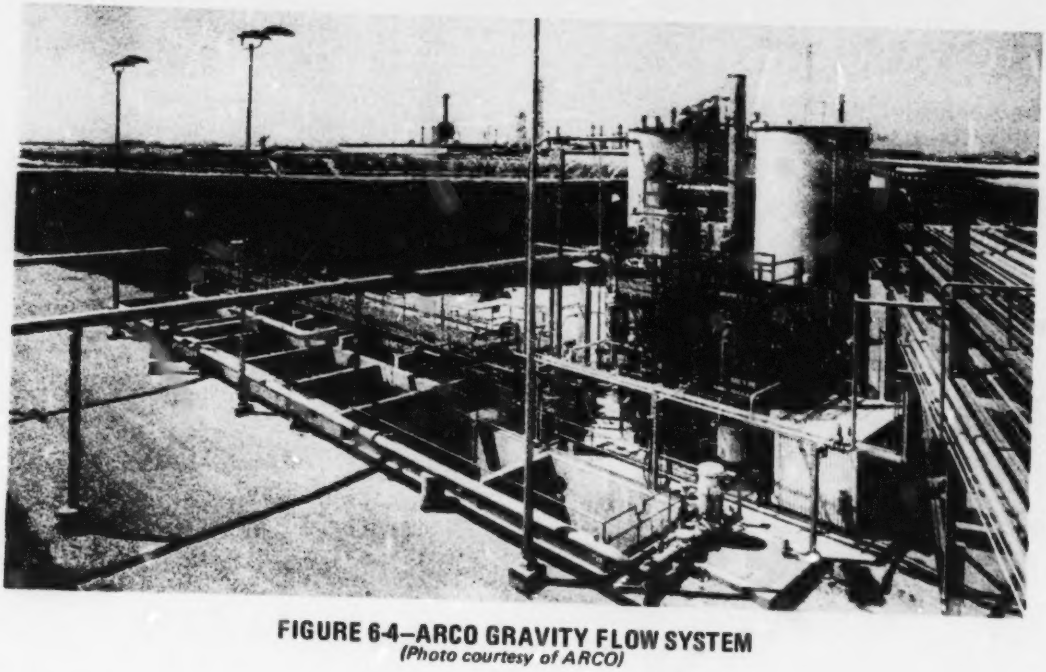

FIGURE 6-4—ARCO GRAVITY FLOW SYSTEM
(Photo courtesy of ARCO)

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CHAPTER 7

EVALUATION AND SELECTION OF CARBONS FOR WASTEWATER TREATMENT

7.1 Introduction

The selection of a suitable activated carbon is an integral part of the design of a carbon treatment plant. As with the design of any type of plant, whether biological or physical-chemical, a careful laboratory and pilot scale testing program must be initiated to help establish an optimum design. However, preliminary testing is probably more important for the case of physical-chemical treatment schemes than for biological designs, since in the former case there is much less published experience to serve as a guide for the design engineer. One of the chief advantages of physical-chemical treatment is its versatility in dealing with a variety of waste streams under changing conditions of flow and organic loading. In order to take full advantage of this versatility, a careful and well-conceived preliminary testing program is a necessity.

This chapter emphasizes the testing and selection of the carbon to be used for wastewater treatment. However, it is necessary to consider also the character of the wastewater and the degree of pretreatment necessary before a particular waste can be applied to the carbon. All of these aspects shall be considered individually first, and then will be integrated into a discussion of pilot testing programs.

7.2 Wastewater Characterization

In order to gain some idea about the carbon adsorbability of the dissolved organics in a wastewater, these organics must first be characterized in at least very general terms. Although industrial or other unusual components in a municipal waste stream should be investigated where necessary, it is usually sufficient to consider only the gross organics and solids in the wastewater. The most common analytical handbook is, of course, "Standard Methods for the Examination of Water and Wastewater," (13th edition, 1970).

7.2.1 Dissolved Organic Parameters

Dissolved organics are operationally defined as those which pass a 0.45-micron membrane filter. It is frequently important to isolate the dissolved fraction of the total organics, since carbon columns function as filters and biological contactors as well as adsorbers. However, in low turbidity solutions, as for example in well-clarified waters, little or no filtration may be necessary prior to analysis.

The chemical oxygen demand (COD) is the usual routing organic analysis. Total organic carbon (TOC) (which can be done quite rapidly) would be preferred except for the expensive instrumentation required. Biochemical oxygen demand (BOD) is in general a parameter of lesser interest from the carbon-testing point of view, but since effluent standards usually include a BOD requirement, BOD does warrant some attention. In industrial or other specialized wastes, specific organic compounds may be identified as principal constituents of the wastewater and these should be singled out for investigation.

Another organic parameter of interest in some situations is color. Color could be indicative of either a specific waste constituent or merely be a general index. Ultraviolet absorbance may also be used as an index of dissolved organics in a relatively clean water ($\leq$ 5 JTU turbidity).

7.2.2 Other Parameters

Some non-organic fractions are also pertinent for wastewater characterization. The filtration function of a carbon column is naturally affected by influent solids. Since solids frequently slough off of a carbon during operation, the influent and effluent from any carbon process should be characterized specifically for suspended solids and turbidity. Materials such as activated sludge, bacterial slimes, chemical precipitates (from a preclarification step) should be noted. These various kinds of solids all may affect headloss buildup in the carbon and thereby increase backwash frequency. It should be recognized that some solids may be sticky and tenacious and hence difficult to remove from the carbon, while others are more nearly inert and easy to deal with. Microbial parameters such as viruses, bacteria, and perhaps algae may warrant attention. The biological contribution to carbon treatment may be affected by toxic elements, as would be true in any biological system. The pH of the feed stream may directly affect adsorption, however, only a few compounds have been studied for pH effects on their adsorption by activated carbon. The economics of pH adjustment to enchance carbon treatment of wastewater have not been investigated, but the pH effect may be important in industrial waste treatment.

7.3 Pretreatment Requirements

Once the wastewater has been roughly characterized as described above, the pretreatment requirements for carbon adsorption can be established. When carbon is being used as a tertiary process, the secondary effluent being treated may require no more than a filtration step. If the activated sludge or trickling filter process is well operated and not overloaded, filtration may not be necessary. When carbon is being used as a secondary process, clarification and filtration are frequently necessary to prevent excessive headloss development in the carbon columns. Although expanded upflow carbon columns do not suffer from excessive headloss, it is advisable to give them a prefiltered feed anyway. These upflow carbon columns do not remove a great fraction of influent solids and prefiltration would be necessary to ensure a product water of acceptable clarity.

7.4 Adsorption Isotherm Tests

The isotherm test is a good preliminary laboratory test to aid in determining whether carbon treatment can be applied to a particular wastewater. However, it should not be used by itself to establish design criteria for a plant. It is also useful in selecting a particular carbon, although even in this task other selection criteria should be applied.

7.4.1 Selection of Candidate Adsorbents

Although there are a fair number of manufacturers of granular activated carbon, many of their carbons are not necessarily suited for municipal wastewater treatment. In addition, some wastewater carbons have an advantage over others in adsorption capacity, physical durability, operating characteristics, or cost. All candidates should be fairly tested by several criteria, since process cost depends upon much more than adsorbent cost. Product quality is, of course, a factor which may supersede cost considerations in some cases.

7.4.2 Preparation of Candidate Adsorbents

The isotherm test applies to either granular or powdered adsorbents, however, the test works satisfactorily only on a powdered sample. Granular carbon must be pulverized until all particles pass a 325-mesh screen and a representative sample must be taken of the powder.

7.4.3 Design of the Isotherm Test

An adsorption isotherm is a batch adsorption test performed in the laboratory under standardized conditions. It will be valid only for the temperature at which it is run, which should correspond to the temperature normally encountered in the wastewater. The isotherm test actually consists of a series of individual batch tests which differ only in one respect, e.g., carbon dosage. Different carbons may also be compared by running their respective series of batch tests at the same time, or in succession using the same batch of feedwater. Each individual batch best is run in a shaker or beaker with an attached mixer. Organics are measured before and after contacting the feedwater with the carbon. Interpretation of the test results is discussed below.

The wastewater used for the isotherm test should be the same feed as that to be treated in the full-scale plant. If preliminary chemical clarification is planned, then the isotherm feed should be clarified with the same coagulant at the same pH, and then readjusted to whatever pH is deemed suitable for plant operation and discharge.

Selection of carbon dosages may be somewhat arbitrary at first. It is usually necessary to run several tests in succession to identify the range of dosages which will give the best isotherm results. The final isotherm plot must consist of adsorption data collected at one time on the same batch of wastewater. Either TOC or COD is an acceptable organic parameter by which to evaluate the results of an isotherm test.

The procedure for the isotherm test need not be described in detail here since it may be found in many places in the literature. The references listed at the end of the chapter may be consulted for procedures on isotherm testing, determination of iodine and molasses numbers, and evaluation of several other physical parameters of activated carbon.

7.4.4 Interpretation

The adsorption data may be evaluated by using a logarithmic plot of: organics removed per unit dose of adsorbent versus residual organic concentration. The following example should serve to describe the procedure:

Carbon dosage (M) (g/l)	Residual COD (C_f) (mg/l)	$X = C_o - C_f$	X/M
0	130 (=C_o)	–	–
0.25	86	44	176
0.50	73	57	114
1.00	69	61	61
2.50	45	85	34
5.00	33	97	19

plot log X/M versus log C_f

The plot is shown in Figure 7-1. The isotherm plot should be linear, but frequently deviates from this ideal. Straight lines may be drawn through many data sets without trouble. Individual deviant points may be discarded as a matter of judgment. Non-linear or completely scattered sets may require a least-squares fitted line; however, it could be argued that any data set which truly requires a least-squares line is probably worth redoing. The success of isotherm testing rests with strict attention to procedural detail.

Once a straight line of fair precision has been drawn, it is extrapolated towards the right to the C_0 intercept. The resulting ordinate, here 450 mg COD/g carbon, is a measure of adsorption capacity. The slope of the isotherm line may also be used to characterize the adsorption operation being tested. Steeper slopes indicate good adsorption of organics present in solution at higher concentrations but not at lower concentrations. Slight slopes indicate comparable adsorption over the entire range of organic concentrations. Higher slopes generally indicate that greater adsorption efficiency in column operations can be expected.

Iodine and molasses numbers are also measures of adsorption capacity, as has been noted previously. These numbers are determined by batch adsorption tests on standard solutions. Literature on both isotherms and iodine and molasses numbers, as well as other carbon testing procedures, is given at the end of the chapter.

7.5 Other Criteria

Isotherm testing may not resolve the issue of which carbon to use, although it may eliminate many candidates. Therefore, some further non-adsorptive selection criteria may prove useful. It is important to note the physical characteristics of the carbon; the manufacturers' specifications may or may not be adequate measures of these characteristics. These may include: (a) density (lighter carbon may be lost during backwashing); (b) fines, either in the original batch, or produced by abrasion of the carbon during handling, operation, and backwashing (fines are ultimately carbon lost, and may also contribute to buildup of headloss); (c) regenerability (carbon losses during regeneration, degree of regeneration, ash production and buildup). Carbon size (12x40 and 8x30 mesh are standard sizes) may be a significant factor only with respect to headloss buildup. Cost of the adsorbent, as noted previously, is only one factor in determining process cost, and need not be decisive unless all other factors are equivalent. Many of these factors cannot be tested directly, and the experience of others must be relied upon.

7.6 Pilot Plant Testing

The tests described above should suffice in most cases to select the best carbon for a particular wastewater treatment application. However, in order to precisely define design criteria for a given carbon plant, it is still necessary to conduct pilot testing. Important design parameters have been discussed in previous chapters, so it is sufficient here to discuss only those factors which can be determined by pilot scale testing.

7.6.1 Conduct of Pilot Operations

Full-scale plant conditions and features must be simulated. The scale of the pilot study is somewhat arbitrary, but some lower limits can be set. Carbon columns probably should be no smaller than 4-inch inside diameter so as to avoid short-circuiting of the flow.

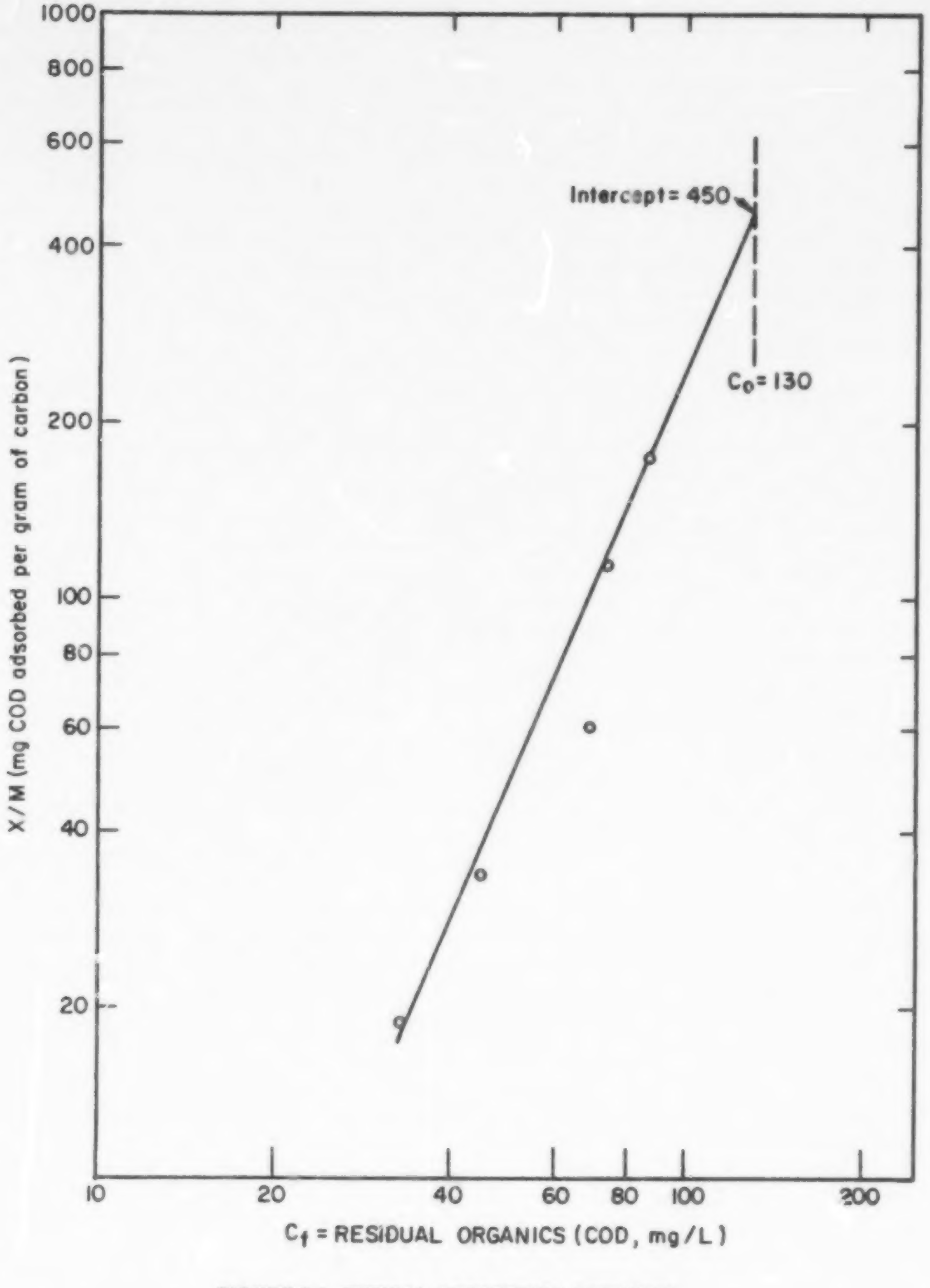

FIGURE 7-1–TYPICAL ADSORPTION ISOTHERM

Packing of carbon columns is frequently a messy business. It is essential to deaerate the pores of the carbon to obtain proper packing density and to eliminate anomalous adsorptive effects. This can be done in several ways: slurrying in boiling (and thus deaerated) water, accompanied by stirring to expel entrapped air; or, saturation of the dry carbon with CO_2 gas. In the slurrying method, the wetted deaerated carbon is then transferred to a contactor partially filled with water, keeping the water level above the carbon level. In the CO_2 method, the carbon is packed dry into the contactor, which is then saturated with CO_2 gas to displace the air, and finally wetted and flushed with cold water (the entrapped CO_2 being dissolved in the water and flushed out). The latter method is obviously the easiest if CO_2 is available. Frequently, it is sufficient to allow the carbon to remain submerged overnight, as is done in full-scale plants. Once the carbon columns are wetted and packed, they must be backwashed to expel the carbon fines.

7.6.2 Monitoring

Monitoring of the pilot columns should consider the following questions. (a) The degree of organic removal is possible over a range of contact times. TOC or COD analyses are sufficient, but some BOD data may be instructive. Samples should be collected at several different carbon depths to determine optimum contact times. Influent samples should be composited if flow variations warrant this, but carbon effluents may require only grab sampling. A rough mass balance is advisable to define the organic removal capability. (b) The adsorptive capacity of the carbon. The isotherm test results cannot be extrapolated to pilot operation. Since biological treatment seems to be an important factor, the length of the pilot study may tend to become extended. Some recent pilot studies with considerable biological treatment contributions have run for 5000-7000 bed volumes with little or no loss in organic removal capability, so judgment is important here. Obviously a "premature" halt to pilot studies will give a conservatively low estimate of carbon capacity and a conservatively high estimate for frequency of regeneration and carbon inventory. (c) Aerobic versus anaerobic biological treatment. Injection of air or oxygen can help settle this question; the principal deciding factor may be odor (e.g. sulfides). Sulfides have not been discussed in detail in this manual because no specific recommendations can be made to combat them. Despite this inattention, they must be reckoned with in considering carbon treatment performance. In general, they may be counteracted by elimination of anaerobic conditions in the contactor. Several methods have been suggested to control sulfides, although none has been tested extensively. These include oxygen injection into the feedwater or the upstream portion of the contactor, chlorination of the feedwater to inhibit biological growth, and frequent backwashing of the contactors affected. At present no firm recommendation can be made beside suggesting that pilot plant operations should evaluate the extent of the sulfide problem and ways of countering it. (d) The effect of solids on carbon performance. Various kinds of solids should be distinguished where appropriate, e.g., residual coagulant, activated sludge fragments, microbial growths. (e) The rate of buildup of headloss. This is the usual criterion for determining backwash frequency. The need for surface wash or air scour during backwash should also be assessed. If headloss development appears excessive, expanded upflow columns may be in order; if this is the case, these units may require prefiltration and/or postfiltration.

One aspect which cannot be piloted is the regeneration step. No small furnaces exist for such purposes other than laboratory models, which may not give results suitable for extrapolation to larger scale.

The selection of an hydraulic loading may be somewhat arbitrary. Whenever possible, pilot columns with different hydraulic loadings should be run in parallel, however, experience indicates that no difference in treatment performance may be noticed within the range 2-10 gpm/sq ft. The selection of a design hydraulic loading may largely depend on operational factors such as headloss development, maximum permissible expansion of an upflow bed, or the choice of gravity versus pressure flow.

7.6.3 Interpretation of Pilot Data

The series of questions raised in the monitoring section above has already covered many aspects of interpretation, some of which are self-explanatory. However, it may be convenient to discuss some modes of data presentation. For example, COD removal over the long term is indicative of carbon treatment performance in general. Mass of COD removed per unit weight of carbon, and carbon dose in pounds per million gallons are measures which may be compared to published data and used to calculate carbon requirements, regeneration frequency, and process cost (see Chapter 6).

The following literature may be helpful in understanding isotherms and other carbon evaluation methods.

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CHAPTER 8

PERSONNEL REQUIREMENTS

Physical-chemical treatment plants are rather complex since they involve a great variety of different unit operations, some of which may be relatively sophisticated. Carbon adsorption systems themselves include several different unit processes, some of which are quite unknown in conventional wastewater treatment plants. For this reason, the quality of operator training in carbon plants must necessarily be somewhat higher than in conventional plants.

In order to realize the fullest capability of the carbon adsorption system, operators should be given specialized training in the practical aspects of the plant operation, including on-the-job training under the guidance of professional performance. An additional requirement for most efficient plant control is the institution of a formal operational procedures manual to help the plant personnel operate the plant at peak efficiency at all times. The very existence of an advanced waste treatment plant implies that the community being served has required that a consistently high quality effluent be produced at all times. Thus the casual attention frequently paid to conventional plants cannot be tolerated at carbon treatment plants.

Since a carbon adsorption system is usually part of a PCT plant or biological plant (as a tertiary stage of treatment), the carbon plant's personnel requirements cannot be considered in isolation from those of the larger plant. All plant personnel will necessarily have responsibilities covering a variety of unit processes. Since not many carbon plants have been operated at full scale to date, there is not much available experience on which to base the planning of personnel requirements. The tertiary plant at South Lake Tahoe represents the bulk of our experience in judging personnel requirements.

In this chapter, we shall confine ourselves to listing the principal tasks involved in the operation of a carbon plant, and then give a reasonable estimate of the number of personnel required.

The operation of a carbon adsorption system may be broken down into the following specific tasks:

1. Carbon contacting
    a. monitoring of flow into the system, in order to recognize surges in flow, solids, or organics, and thereby anticipate operating difficulties caused by these situations;
    b. monitoring of effluent quality to assure that treatment performance standards are being realized;
    c. routine maintenance to pumps, valves, piping, monitoring instruments and sampling systems.
2. Backwashing (in downflow columns)
    a. monitoring of headloss or effluent turbidity where these criteria have been selected to determine backwash frequency;

b. valving operations to backwash the columns.

3. Carbon dewatering and transport

   a. removal of the contactor containing spent carbon from service and its replacement with a fresh contactor (in multi-stage systems, each contactor in the series must be also moved up in sequence and the fresh contactor placed at the end of the series);

   b. removal of the spent carbon from the contactor;

   c. dewatering of the carbon via a drain bin, screw conveyor, etc. (this may be largely unattended except for monitoring of the free flow of the carbon and the degree of dewatering obtained prior to entry into the furnace);

   d. maintenance of pumps, valves, dewatering devices.

4. Carbon regeneration

   a. scheduling of furnace operation to correspond with the exhaustion rate of the activated carbon;

   b. setting and monitoring of furnace conditions necessary for proper regeneration, such as temperature, fuel requirements, flow rate and moisture content of the incoming carbon, etc.;

   c. monitoring of exhaust gas system to insure proper air pollution control and to check on furnace operation;

   d. monitoring of the characteristics of the regenerated carbon to guard against either incomplete regeneration or excessive burnoff of the activated carbon;

   e. maintenance of the furnace and its auxiliary equipment;

   f. monitoring of transport of the regenerated carbon through the quenching operation to either a storage bin or a spare contactor;

   g. determining the amount of makeup carbon necessary by measuring the difference in carbon volume before and after regeneration;

   h. backwashing of the regenerated carbon to eliminate fines created during regeneration and contributed by makeup carbon.

A reasonable estimate of labor required for operation, maintenance, and laboratory services based on the above list of tasks in a 10 MGD plant is as follows:

Operation:	one man per 8-hour shift (3 man-days per day)
Maintenance:	two men on one 8-hour shift (2 man-days per day)
Laboratory Services:	one man on one 8-hour shift (1 man-day per day)
Total:	6 man-days per day

CHAPTER 9

PLAN & SPECIFICATION REVIEW CHECK SHEET

The processes outlined in this design manual have been developed for application to projects where improved effluent quality is needed or required. In some cases, these processes have had limited use in full-scale design of wastewater treatment facilities. Design engineers and reviewing authorities may not be completely familiar with the parameters to be considered in the preparation of plans and specifications for a given project. The following plan and specification review check sheet has been prepared to serve as a guide to the engineer in the design of proposed facilities which use the process or processes outlined in this manual. It will also be used by the Environmental Protection Agency, and may be used by State and local authorities in their review of projects for approval.

As with the case of any check sheet, its purpose is to fully consider all possible parameters for an individual process. For a given project all or part of the check sheet may be applicable and should be used with this fact in mind.

PLAN & SPECIFICATION REVIEW CHECK LIST

GENERAL

Applicant ______________________ Project No. ______________

Design Engineer ______________________ Address ______________

Reviewing Engineer ______________ Review Date ________ Approval Date ________

Type of Waste Domestic Industrial (Type) ________ Other ________

Volume of Flow Present ______________ Design ______________

Organic Loading Present ______________ Design ______________

Turbidity Loading Present ______________ Design ______________

Suspended Solids Loading Present ______________ Design ______________

PRE-TREATMENT

Screening ____

Comminutor ____

Grit Removal ____

Flow Measurement ____

Primary Sedimentation____

No. of Tanks__________ Volume____________

Detention Time______ Present________________ Design________________

Surface Settling Rate___ Present________________ Design________________

Overflow Rate_______ Present________________ Design________________

Chemical Clarification – Number of Units

Chemicals	Dosage	Mixing Time
1.		
2.		
3.		

Flocculation Time Present________________ Design________________

Clarification Time Present________________ Design________________

Rise Rate Present________________ Design________________

Overflow Rate Present________________ Design________________

Biological Treatment

Type______________________ Modification______________________

Alternate Modes of Operation______________________________

Number of Units____________________________________

Retention Time_____________________________________

ACTIVATED CARBON TREATMENT

Type of Carbon__________ Powdered______________ Granular______________

Carbon Capacity__________ lbs Carbon/lb Organic Load________________

Carbon Dosage__________ lbs Carbon/MG of Water

Diurnal Fluctuation in Flow________________ in Organic Load________________

Granular Systems

__________ Up Flow____________ Down Flow ____________ Other

Number of Units__________ in Parallel______________ in Series______________

Unit Dimensions: Bed Depth________ Width ________ Shape________

Hydraulic Loading ________

Contact Time Per Unit ________ Total Contact Time ________

Distribution System ________

Collection System (Under Drains) ________

Free Board ________

Backwash Rate ________ Bed Expansion ________

Pressure System ________ No. of Pumps ________

Gravity System ________ Available Head ________

Powdered Systems

Number of Units ________ in Parallel ________ in Series ________

Dimensions: Diameter ________ SWD ________ Freeboard ________

Flocculation Time ________ Clarification Time ________

Rise Rate ________ Overflow Rate ________

Carbon Slurry Concentration

1st Stage Unit ________ 2nd Stage Unit ________

Hydraulic Transport of Carbon

Pipe size and Material ________ Velocity ________

Slurry Concentration ________ Types of Valves ________

Types of Pumping Devices ________

Regeneration

Type of Furnace – Multiple Hearth, fluidized bed, etc.

Furnace Dimensions ________ Fuel Requirements ________

Carbon Regeneration Rate ________ Carbon feed control rationale ________

POST TREATMENT

Sedimentation ________ Filtration ________ Chlorination ________

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APPENDIX A

GLOSSARY

Abrasion Number – The abrasion number of granular carbon is measured by contacting a carbon sample with steel balls in a pan on a Ro-Tap machine. The abrasion number is the ratio of the final mean particle diameter to the original mean particle diameter (determined by screen analyses) times 100.

Adsorbate – Those materials, e.g., color bodies, taste and odor compounds, or other solutes, which are adsorbed on an activated carbon or other adsorbent.

Adsorbent – A material, such as activated carbon, upon which adsorption takes place.

Adsorption Isotherms – A measurement of the adsorptive capacity of an adsorbent as a function of the concentration, or pressure, of the adsorbate at a given temperature. It is the constant temperature relationship between amount adsorbed per unit weight of adsorbent and the equilibrium concentration, or partial pressure.

Apparent Density – The weight per unit volume of a homogeneous activated carbon. To assure uniform packing of a granular carbon during measurement, a vibrating trough is used to fill the measuring device. See also bed density.

Ash – The mineral constituents of activated carbon. It is normally expressed on a weight percent basis after a given amount of sample is reduced to ash.

Average (Mean) Particle Diameter – This is a weighted-average diameter of a granular carbon. A sieve analysis is run and the average particle diameter calculated by multiplying the weight of the fraction retained on each sieve by the sieve's mesh size, adding the products, and dividing by the total weight of the sample. The average size of each fraction is taken as the size midway between the sieve opening through which the fraction has passed and the sieve opening on which the fraction was retained.

Bed Density, Backwashed and Drained – The weight per unit volume on a dry vasis of a bed of activated carbon that has been backwashed and drained. This value is usually lower than the corresponding apparent density due to the classification according to size of the carbon granules during backwashing.

Bed Depth (Height) – The total depth of carbon which is parallel to the flow of the stream and through which the stream must pass.

Bed Diameter – The diameter of a cylindrical carbon column, measured perpendicular to the stream flow.

Breakthrough Curve – A plot showing the relationship between the cumulative volume of liquid passed through a carbon column and the effluent concentration of the component being removed.

Contact Time – The time required for the liquid to pass through a carbon column assuming that all the liquid passes through at the same velocity. It is equal to the volume of the empty bed divided by the hydraulic loading.

Countercurrent Operation – Any contacting process, e.g., adsorption, where the flows of influent wastewater and solid adsorbent proceed in opposite directions. The highest concentration of dissolved organics contacts the most nearly exhausted portion of the adsorbent, while the virgin adsorbent contacts only the lowest concentration of organics. The purpose of such a system is to take fullest advantage of the adsorptive capacity of the nearly exhausted adsorbent. See under Moving Bed.

Effective Size – The sieve size which will permit 10 percent of the carbon sample to pass but will retain the remaining 90 percent. It is usually determined by interpolation on a cumulative particle size distribution curve.

Fixed Bed – An adsorption process in which liquid being treated is allowed to pass through a confined bed of carbon until the carbon becomes exhausted before the unit is removed from service and completely recharged with fresh carbon. The carbon remains fixed in position during the adsorption process.

Freeboard – The elevation of the top of the contactor or wash trough in the case of gravity systems above the surface of the carbon.

Hardness Number – This is the Chemical Warfare Service (CWS) test. The hardness number is a measure of the resistance of a granular carbon to the degradation action of steel balls in a pan in a Ro-Tap machine. It is calculated by using the weight of granular carbon retained on a particular sieve after the carbon has been in contact with steel balls.

Hydraulic Loading – The quantity of flow passing through a column or packed bed expressed in the units of volume per unit time per unit area; e.g., gpm/sq ft (superficial velocity).

Iodine Number – The iodine number is the milligrams of iodine adsorbed by one gram of carbon at an equilibrium concentration of 0.02N iodine. It is measured by contacting a single sample of carbon with an iodine solution and extrapolating to 0.02N by an assumed isotherm slope. Iodine number can be correlated with ability to adsorb low molecular weight substances and with the total area of pores having openings less than 10 angstroms in diameter.

Losses on Regeneration – The loss of original carbon during regeneration due to the burning off or mechanical abrasion of the carbon. Losses are usually 5-10% (includes all losses) for coal-based carbons.

Make-up Carbon – Fresh granular activated carbon which must be added to an adsorption system after a regeneration cycle or when deemed necessary to keep the total amount of carbon constant. This is to replace carbon lost during regeneration and elsewhere during handling.

Methylene Blue Number – The methylene blue number is the milligrams of methylene blue adsorbed by one gram of carbon in equilibrium with a solution of methylene blue having a concentration of 1.0 mg per liter.

Molasses Number – The molasses number is calculated from the ratio of the optical densities of the filtrate of a molasses solution treated with a standard activated carbon and one treated with the activated carbon in question. The molasses number can be correlated with the capacity to absorb many high molecular weight substances and with the total area of the pores having openings greater than 10 angstroms in diameter.

Moving (Pulsed) Bed – A moving bed incorporates an effective countercurrent operation within a single column. This is accomplished by the removal of spent carbon from one end of the carbon bed and the addition of carbon at the other end. The flow of liquid and carbon are in opposite directions; usually the carbon moves downward and the liquid upward.

Particle Density, Wetted in Water – The density of carbon in water assuming all pores to be filled with water. The value can be calculated by use of the real density of the activated carbon and the pore volume.

Particle Size Range – Usually, this term refers to the sizes of the two screens in the U.S. Sieve Series (occasionally in the Tyler Series) between which the bulk of a carbon sample falls. For example, 8 x 30 means most of the carbon passes a No. 8 screen but is retained on a No. 30 screen.

Particle Size Distribution – The particle size distribution in a given sample is obtained by mechanically shaking a weighed amount of material through a series of test sieves. It is a statement of the weights retained on each of the series of sieves.

Physical-Chemical Treatment (PCT) Plant – A treatment sequence in which physical and chemical processes are used to the exclusion of explicit biological processes. This does not exclude incidental biological treatment obtained on filter media or adsorptive surfaces. In this sense, a PCT scheme is a substitute for conventional biological treatment and produces an equivalent product quality. A PCT scheme following an existing biological plant may by contrast be called simply a tertiary plant, although it is also PCT in a general sense.

Pore Size Distribution – A measure of the pore diameters which gives activated carbons their unique adsorptive properties. Cumulative distributions give the relationship between pore size, diameter or radius, and volume in pores smaller (or larger) than that size. Derivative distributions indicate the amount of volume in pores between certain close sizes. Pore size distributions in the small pores are calculated from nitrogen adsorption isotherms while distributions in the macropores are measured with the mercury porosimeter.

Pore Volume – The sum of the macropores and micropores in a carbon, or, i.e., the total pore volume. This is expressed as volume per unit weight of carbon.

Real Density – The density of the carbon granule itself. This is determined by helium displacement. It is usually close to that for graphite. In the metric system it is the same as specific gravity.

Surface Area of Adsorbent – This is the surface area per unit weight of carbon. The surface area of activated carbon granules is usually determined by the nitrogen adsorption isotherm by the Brunauer, Emmett and Teller Method (BET Method). Surface area is usually expressed in square meters per gram of carbon. Typical values for commercial carbons are given in Table 4-1.

Total Organic Carbon (TOC) – The TOC is a measure of the amount of organic material in a water sample expressed in mg carbon per liter of solution.

Uniformity Coefficient – This is obtained by dividing the sieve size which will pass 60% of a sample by that which will pass 10% of the sample. These values are usually obtained by interpolation on a cumulative particle size distribution plot.

Voids In Packed Beds – The volume between the carbon particles in a packed bed or column expressed as a percentage of the total bed (carbon) volume.

APPENDIX B

CARBON REGENERATION FURNACE SPECIFICATIONS

I. GENERAL

A. Scope

1. This specification covers the design and construction of a multiple hearth furnace having the primary function of regenerating spent activated carbon. Insofar as possible, the furnace with its accessories shall be designed for convenient access and for east in maintenance and parts replacement. (Figure B-1.)

2. All machinery and other places of physical hazard shall be properly and permanently guarded to meet in full all provisions of Safety Standards imposed by Federal, State and Local regulations and codes.

II. DESIGN DATA

A. Spent Activated Carbon Characteristics

1. Feed Rate	80 lb to 110 lb/sq ft/day
2. In the Wet State (Drained)	Abrasive
3. Precent Moisture, In Feed	Wet Basis 40-50% by weight
4. Precent Moisture, Permissible in Regenerated Product	0%
5. Density (Apparent-Spent)	0.60-63 gm/cc
6. Particle Size	8 x 30 mesh
7. Specific Heat of Granules	0.22 BTU lb/°F
8. Temperature of Slurry at Feed	Ambient
9. Drying Temperature	60°–212°F
10. Baking Temperature	212°–1500°F
11. Temperature of Granules at Discharge	1500°–1650°F
12. Activating Gas Temperature	1700°–1800°F

B. Site Description

1. The location factors which could influence the design, operation and satisfactory operation of the equipment include the location (mounting) elevation above mean sea level, maximum and minimum local summer and winter air temperatures.

REFERENCE 1

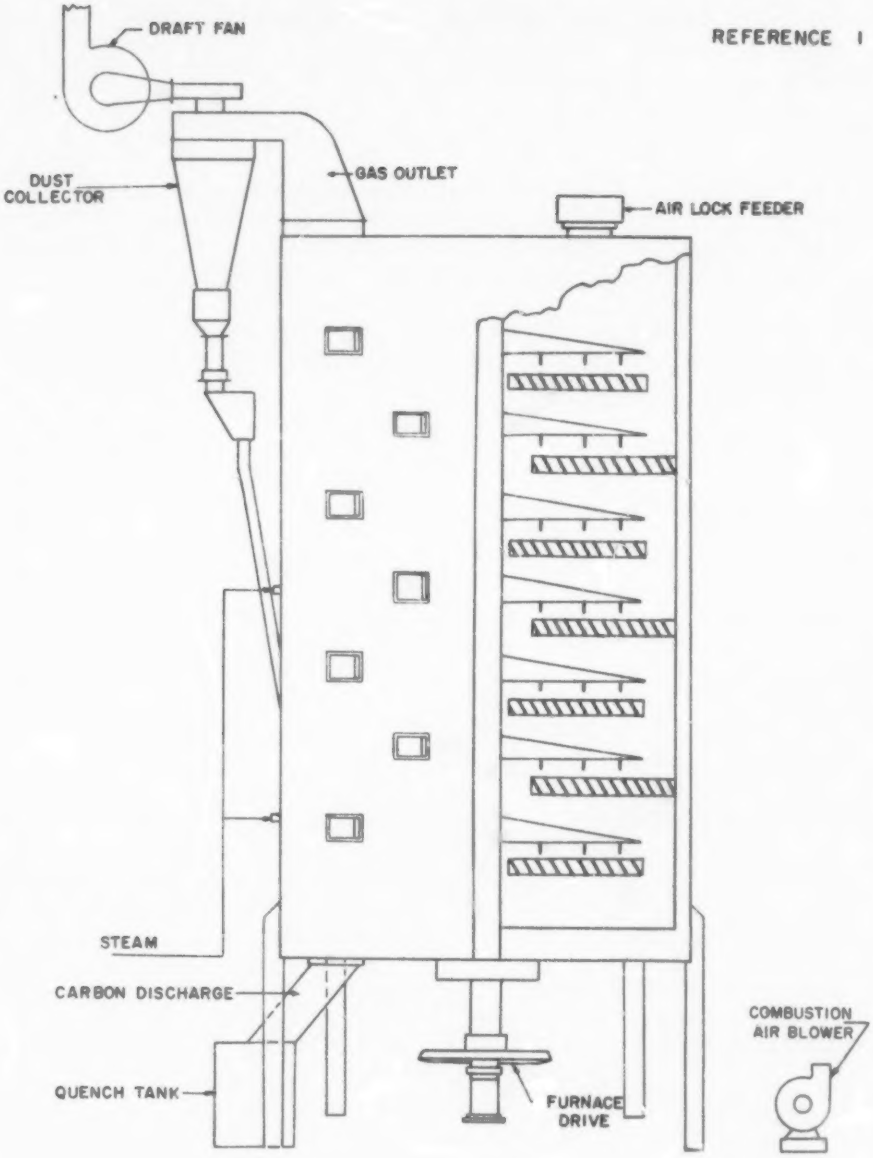
DRAFT FAN
DUST COLLECTOR
GAS OUTLET
AIR LOCK FEEDER
STEAM
CARBON DISCHARGE
QUENCH TANK
FURNACE DRIVE
COMBUSTION AIR BLOWER

FIGURE B-1–REGENERATION FURNACE

III. DESIGN SPECIFICATIONS

A. General

1. Furnace shall be able to accommodate shutdowns due to power failure. This necessitates that the furnace shall be (a) able to start up again fully loaded, and (b) able to withstand the latent heat so that warpage will not occur.

2. Plant Operating Schedule – 365 days/year.

3. Furnace Utilization – Continuous

4. Feed Cycle – Idle time may vary from two to four hours during change over from one pressurized contactor to another.

5. Heating Fuel – Natural Gas @ 1000 BTU/cu ft .
   or Manufacturers Gas
   or Propane Gas

6. Actual Firing Rate Required (Design) – By Vendor

7. Material Retention Time – By Vendor

IV. EQUIPMENT

A. General

1. The multiple hearth furnace shall be direct gas fired vertical refractory-lined cylinder with a series of horizontal hearths positioned one above the other and rotating central shaft with rabble arms for each hearth. Inlet to be at the top and discharge from the bottom of the furnace. The combustion space shall be of sufficient volume to insure a heat release rate which shall be reasonable and commensurate with accepted practices for refractory furnaces. Means of control of the combustion air shall be provided so that accurate regulation for its use in selective oxidation of the impurities and contaminates contained in the carbon may be accomplished. Simple draft and means to maintain the draft shall be provided to insure complete combustion of impurities and fuel introduced into the burning zone. Temperature in the combustion zone shall be maintained from sixteen hundred degrees F minimum to, but not exceed, nineteen hundred degrees during periods of abnormal operation.

   All materials used in the fabrication and construction of the furnace and auxiliary equipment shall be new and of the best quality for the purpose intended and shall meet in full the applicable specifications of the American Society for Testing Materials, as listed below:

Structural Steel	A 36-70a
High Tensile Bolt	A 325-66b
Gray Iron Castings (Class to suit service)	A 48-64
Malleable Iron Castings	A 47-66T
Wrought Iron	A 207-66
Refractories for Incinerators Type A (Type as suited to service)	C 106-67
Refractories Mortar	C 178-47

High temperature resisting Chromium-Nickel-Iron Alloy castings shall conform to ASTM Standard Specifications for Chromium-Nickel-Iron Alloy Castings (25-12 Class) for high temperature service, Designation A-447-50 (Type 11).

All fireclay brick shall conform to the specified dimensions as to size within permissible deviation of not to exceed plus or minus 2 percent on dimensions of four inches or over, or not to exceed plus or minus 3 percent on dimensions under four inches and shall meet all requirements of ASTM Designation C64-61, Col. 6.

2. The steel shell, top cover and bottom plate shall be steel plate conforming to ASTM Designation A 36-70a. All welds shall be continuous. Field connections shall be with high tensile bolts. The structural steel supporting structure shall be of welded construction, and designed to rigidly support the furnace and central shaft.

3. The furnace shall be lined with sufficient first quality firebrick refractory, insulating refractory and mineral wool to produce a furnace surface temperature of not more than 150° F.

   The firebrick and hearth tile shall conform to ASTM C 64-61, Col. 6. The refractories shall be bonded with high temperature air setting cement conforming to ASTM Designation C 178-47.

4. The central shaft and rabble arms shall be made of 25/12 stainless steel conforming to ASTM Designation A 297-65. The shaft shall be hollow and designed for natural draft cooling.

   The central shaft shall be supported by a heavy duty bearing support and rotate on a thrust bearing. A dust cover shall be provided to protect the bearing and suitable lubrication fittings and lubrication included. The central shaft shall be guided at the top by a heavy cast iron guide bearing which can be adjusted in any horizontal direction. The design shall permit free vertical movement of the central shaft from expansion. Lubrication fittings shall be provided for the top bearing.

   The central shaft shall be suitably sealed at the furnace top and bottom to prevent air leakage out of the furnace.

5. Rabble arm shall be cast as a solid piece with teeth cast onto the arm. The four arms per hearth shall be cast on the central shaft and lock into place with a pin on the shaft.

6. Lute caps of 25/12 stainless steel, ASTM Designation A 297-65, shall be provided to prevent leakage of carbon and short-circuiting of gases on "Out" hearths.

7. The central shaft shall be driven through a cast beveled gear and pinion of high strength cast iron. The pinion shall be mounted on the output shaft of a heavy duty gear reducer which shall be driven in turn by a variable speed drive with an electric motor. The complete furnace drive and shaft shall be mounted on a fabricated steel base.

8. Each hearth shall be provided with one refractory-lined cast iron door and frame of

not less than 1 1/4 sq ft in area. The doors, frame, and adjustable observation ports shall have machined faces and be provided with asbestos gaskets and quick-opening latching device to prevent leakage.

9. A flanged feed inlet shall be provided on the top of the furnace and a flanged product outlet shall be provided on the bottom. Thermocouple openings shall be provided on all hearths as required for temperature recording and controlling.
10. The furnace shall be equipped with inlet nozzles for steam injection, complete with valves, piping and fittings.

V. AUXILIARY EQUIPMENT

A. Burner System

1. The furnace shall be provided with sealed gas burners for natural or bottled gas. The furnace burner system shall be capable of regenerating granular activated carbon at a rate of (to be specified in the design).
2. Each burner shall be easily adjustable to provide a constant air-gas ratio over its complete firing range. It shall be possible to set the air-gas ratio such that the products of combustion from each burner can be accurately maintained at any point between 0 and 5% oxygen on a volume percent basis.
3. A combustion air blower shall be provided complete with filter and direct-connected electric motor.
4. At least one control valve with operator shall be provided on each hearth that is fired such that the temperature on each fired hearth can be closely and independently maintained at any desired temperature up to 1850°F.
5. A complete pilot burner system shall be provided with one pilot for each main burner. The pilot burner system shall be designed to operate continuously and be complete with electric ignition, regulators and valves.
6. All necessary equipment shall be provided to make a flame safeguard system meeting F.I.A. requirements for this type of process furnace. This equipment shall include alarms, relays, push-buttons, etc., that will be mounted away from the burner system in addition to the valves, switches, etc., that must be assembled with the burner system on the furnace.
7. All piping and tubing to interconnect the burner system and flame safety system close to the furnace shall be supplied. All miscellaneous accessories such as pressure regulators, etc., required to make the burner system operationally complete shall be supplied.
8. Two extra burner tiles shall be provided as spare parts.

B. Instrumentation

1. Temperatures shall be recorded on each of the hearths, on the cooling air exhaust, and exhaust gas off-take. Chromel-alumel thermocouples with protection tubes and lead wire shall be provided.

2. One control instrument shall be provided for each fired hearth which is capable of controlling the temperature to plus or minus 10 Fahrenheit degrees from the set point under the specified operating conditions. Chromel-alumel thermocouples with protection tubes and lead wire shall be provided and suitably installed.

3. Alarm horn with silencing relays shall be provided to signal burner shutdown, over-temperature, fuel pressure loss, combustion air pressure loss, power loss and furnace shaft stop.

4. Motor starters shall be provided with push buttons and running lights for all motors.

5. A weatherproof cubicle shall be provided with all above equipment mounted, piped and wired. It shall also mount the start and stop buttons and indicating lights for the furnace burners, a main circuit breaker and fused circuits for each starter and device. Necessary ultra violet sensing flame safety relays, with faulty burner indicator, shall be provided.

6. Two extra thermocouple assemblies with protection tubes and one each for the following shall be provided as spare parts; U. V. scanner, solenoid valve coils, pilot assembly, atmospheric governor, three spark plugs, and one set spares for flame relay.

7. A portable indicating instrument shall be provided to measure the oxygen level of the gases in the furnace atmosphere.

C. Exhaust Gas System

1. All connecting ductwork shall be fabricated of 316 stainless steel. Expansion joints shall be provided and clean out shall be available upstream from the scrubber.

2. A wet scrubber shall be provided in 316 stainless steel which will effectively reduce the dust loading to meet local air pollution regulations. The scrubber shall be equipped with necessary connections for the plant water supply line and the scrubber effluent line to the plant sewer. Scrubber discharge temperature shall not exceed 100°F.

3. A centrifugal type induced draft fan shall be provided with motor and V-belt drive. The fan shall be constructed of 316 stainless steel and/or cast iron and shall be equipped with a condensate drain.

4. A stack of suitable height shall be provided of 316 stainless steel. The stack shall have a rain cover and be adequately supported complete with roof jack.

5. A manually operated damper shall be provided in the exhaust gas system that can conveniently be operated from the platform.

6. A manometer shall be conveniently mounted where the damper is operated. It shall be connected to the top hearth of the furnace by tubing so the furnace pressure can be observed while the damper is being adjusted.

7. The exhaust gas system shall be insulated with suitable insulation held in place with aluminum sheeting, for personnel protection wherever the metal temperature will be over 175°F.

8. The entire exhaust gas system shall be suitably supported where necessary with structural steel.

9. Ladders and/or platforms shall be provided for access to the scrubber, draft fan and afterburner it not available or reachable from the building floor.

D. Dust Collector System

A complete dust collector system shall be provided with a hood over the quench tank and separate sealed 50 gallon drum.

E. Afterburner System

A refractory-lined afterburner shall be installed between the carbon regeneration furnace gas outlet and inlet to the scrubber precooler to destroy any noxious vapors. The afterburner shall be complete with excess air burner, electrically ignited pilot, blower, automatic temperature controller, ultra-violet scanner and necessary safety relays, control relays, buttons and lights mounted in the local furnace instrument panel.

VI. INITIAL OPERATION

The furnace supplier will be required to have a qualified engineer available to start and adjust the equipment and instruct the plant personnel on its operation and maintenance. This engineer will remain in the plant for a minimum of 10 days or until such time as the equipment is in satisfactory on-stream operation and meeting the performance requirements.

VII. INSTRUCTION MANUALS

The furnace supplier shall furnish 3 copies of a manual giving detailed operating and maintenance instructions prior to the initial operation of the equipment.

Reference

1. B-S-P Bulletin No. 250, Multiple Hearth Furnaces, Bartlett-Snow-Pacific, Inc.

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